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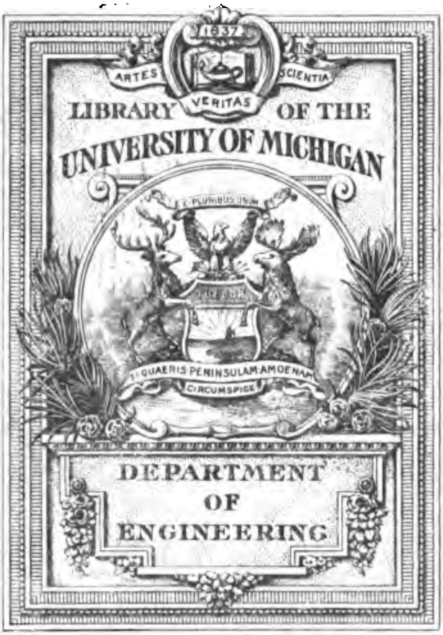
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AN ELEMENTARY TREATISE ON

STEAM AND THE STEAM-ENGINE

STATIONARY AND PORTABLE

35031

(BEING AN EXTENSION OF THE ELEMENTARY TREATISE ON
STEAM OF MR. JOHN SEWELL)

BY D.aniel KINNEAR CLARK,

MEMBER OF THE INSTITUTION OF CIVIL ENGINEERS; AUTHOR OF "RAILWAY
MACHINERY," "A MANUAL OF RULES, TABLES, AND DATA,"
"TRAMWAYS, THEIR CONSTUCTION AND WORKING,"
ETC., ETC.

With Numerous Illustrations

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PREFACE.

In issuing this volume, it is necessary to state that Mr. Sewell's work has been entirely re-cast, and, to a considerable extent, re-written. Much of what was, in the original book, of but general interest, or had become obsolete in consequence of the advances of scientific investigation and of experience, has been replaced by matter more directly interesting to the steam-engineer. The mechanical theory of heat is explained and exemplified, and the heat of combustion is given for various combustibles. An extended notice of peat as a fuel has been supplied; and new chapters on steam, steam-boilers, and stationary and portable steam-engines are added. The action of steam in the cylinders of steam-engines, and the conditions required for economically working steam by expansion, as originally investigated by the Editor, are treated in considerable detail. The compound engine is also discussed, in addition to the various classes of single-cylinder engines; and the most recent recorded performances of portable engines are presented to the reader, together with a summary account of that nearly forgotten class of labouring machines—the traction-engine.

The historical section of Mr. Sewell's work, which is retained in its original form, presents an interesting record o the inception and growth of the steam-engine, embracing period of more than two thousand years.

D. K. C.

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STEAM

AND THE

STEAM-ENGINE,

STATIONARY AND PORTABLE.

CHAPTER I.

HISTORICAL NOTICE OF STEAM AND THE STEAM-ENGINE.

THE genealogy of steam power, like that of heraldry, or science, or mechanics, or manufactures, passes into the romance of antiquity, and is involved in the secrecy of idolatrous worship, which has left only scanty means to trace it.

These means are historical allusions, but chiefly a philosophical treatise on the "Inventions of the Ancients," by Hero of Alexandria, a pupil of Ctesibus, whose time is variously estimated as from 225 to 150 B.C.

Historically, however, since Hero recorded the existence of the steam-engine in an existing language, no retrogression marks its onward progress. An outline, therefore, of its history will more pleasingly convey rudimentary instruction on the application of steam power, than could be done by abstract reasoning. By this plan there is also the advantage of bringing into converse, as it were, the inventive ideas of past and present steam-engine improvers; for Boyle well remarked that failures are as instructive as successes. The practice of seeking to enhance modern science by disparaging that of past ages is too often used, and we regret to find one so eminent as Dr. Lardner attempting to show that the ancients were ignorant of steam, because they described it as "air produced by heat from water."

Following the course usually adopted in giving practical forms to the descriptions of inventors, such as those of the Marquis of Worcester and others, two of Hero's altar-engines will be shown as cranes, with a view of usefully illustrating the romance of steam and hot-air engines.

To make these more clear, Homer's ships, which "plow with reason up the deeps," and Plato's reference to steam, will be first noticed.

Homer, 927 B.C.—It is uncertain how long steam power may have been employed; but in cooking it would early display its force, and lead ingenious minds to apply it otherwise. When the word "steam" was generally used for vapour of water is not known; but Homer speaks of "steam" from roasting meat as it is yet spoken of, and his description of the Phæacian ships is an instance of great power being poetically, if not really, existent.

In Ogilby's edition of the Odyssey, dated 1699, Homer makes the Phæacian Prince thus address Ulysses the Greek—

"Now, Sir, be pleased you would yourself declare,
Where you were born, and what your Parents are,
And your Aboads: that so we may instruct
Our Ship, you to your Country to conduct;
We use nor Helm nor Helms-man. Our tall ships
Have Souls, and plow with Reason up the deeps.
All Cities, Countries know, and where they list,
Through Billows glide veiled in obscuring Mist;
Nor fear they Rocks, nor Dangers on the way,
But once I heard my sire, Nausithous, say
Neptune enraged, because we do transport
So many people safe from Port to Port,
Returning will our vessel sink." * * *

This is a glowing description of navigation, conceived and described about two thousand eight hundred years ago, if not partly realised by some potent agent whose powers seemed illimitable to Homer. In various other passages, when describing Grecian ships, oars only are referred to, as in Ulysses' command to avoid a rock—

> "Sit on your Banks with pliant Oars to sweep,
> All as one man, the surface of the deep;
> But, Helmsman, thy care the vessel must protect."

Paddle-wheel boats moved by manual or horse or other power, and oars, are the only ancient propellers now known besides sails.

If, then, those "renowned Phæacians," or ancient Egyptians, employed neither horse, nor steam, nor other potent motive agent to propel their ships, then Homer conceived and clothed with brilliant language a great idea, all but literally embodied in recent navigation.

From the well-known science of the Egyptians, from Homer's frequent reference to "hecatombs of cattell" sacrificed to propitiate the gods, accompanied by wood, fire, and water to the altar, and completed by libations of wine poured on the sacrifice, as

> "On burning Altars a Libation due,"

we can scarcely doubt but that they were well acquainted with steam power as used in religious services; and as Homer's assertion to Ulysses,

> "Since at Contrivements we are Skilful both
> For dex'trous Sleights, 'mongst Mortals thine's the prize,"

is attested by their existing monuments, it would be easy for such "skilful contrivers" to convert a "wine or water-raising engine" into a stone-raising one useful in the arts.

Plato, 390 B.C.—The prevailing darkness regarding the scientific and practical knowledge of the ancients is in a great measure due to the philosophers of those days, such as Plato, who considered it derogatory to explain science to the uninitiated, or record the inventions of the "vulgar," however meritorious, beyond a passing allusion to them in other subjects.

Plato describes steam as water melted into air by heat, which could be compressed into water again—a very correct description of the generation and condensation of steam, although this word is not used.

He also makes Timæus speak of ingenious inventions in the mechanical arts; and from Plato's particular notice of steam power, it is evident that it was then a familiar object to learned and ingenious men, and may have been equally so in Homer's time. Neither can it be doubted that Aristotle, one of Plato's disciples, who died 322 B.C.; Euclid, the mathematician, who flourished 300 B.C.; Archimedes, the great geometrician and mechanician, who was basely slain 212 B.C., would be all conversant with steam and the steam mechanism of their days.

More particularly in the noble defence of Syracuse against the Romans is Archimedes believed to have employed steam in some of his defensive engines, whilst with his burning-lenses he attacked the invaders, and drew the attention of the world to the resources of mechanical science.

Hero, 150 B.C.—About this time, if not before, Hero of Alexandria wrote his able treatise on the "Invention of the Ancients" of his day, which has associated his name with the invention of the steam-engine, although it appears to have been known some thousand years before his time. Hero states that some of the seventy-eight inventions he describes were his own, but does not specify which they are.

Like other sources of information, extending beyond the burning of the Alexandrian Library of four hundred thousand volumes by the Saracens under Omar, 640 A.D., steam, in all probability, also lost its records. Hero's treatise was written before this dire event, but policy would guide his selections from the records of former inventors, which he professedly gives.

In a commendable spirit of justice, Messrs. Woodcroft and

Greenwood have published a carefully revised edition of Hero's treatise on Pneumatics, which describes and illustrates seventy-eight "ancient inventions."

Many of them are very ingenious, and display a knowledge of the properties of steam, air, and water. Amongst the number are a syphon, a fire-engine pump, a water-clock, steam-engines, altar-libation engines, singing-birds, and other devices, ending in an automaton drinking water after a knife had passed through its neck. They would well repay a careful examination.

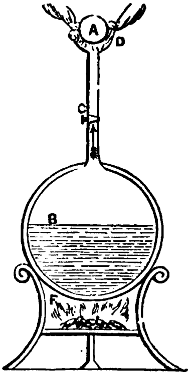

Fig. 1.
Ancient Steam-engine.

Hero's forty-fifth invention, Fig. 1, illustrates the force of steam in raising a weight A out of its seat in D, as it passes up the pipe C from the boiler B, in which it is generated by the fire F, which would also equally move a piston in a cylinder. This is still occasionally a lecture experiment.

Hero's forty-seventh invention, Fig. 2, is designed for the heat of the sun to expand the water in A, and by compressing the air on its surface jointly with the vapour formed, to force the contents in A up the pipe B. When A is cooled, the water in D would rise to fill the partial vacuum in A, and be emptied as before. By substituting a fire below A, instead of the sun above it, we have a simple water-raising engine on De Caus's plan, but wanting the separate cylinders to make it either as complete or economical as the idolatrous engine, Fig. 4.

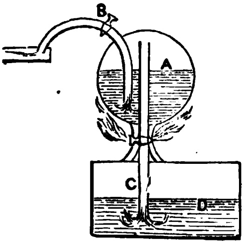

Fig. 2.
Ancient Hot-air Engine.

Hero's fiftieth invention, Fig. 3, is a simple yet complete rotatory steam-engine, capable of giving motion to machinery. The steam generated in A passes up the hollow frame B into the globe C, freely suspended on the point of B and on an opposite centre. The steam then issues at an orifice on one side only of each arm E F, against the air, whose resistance causes these arms to recede in an opposite direction and produce rotation of the globe C. If the steam had issued at both sides of the arms, the resistances would have balanced each other without obtaining rotation, similarly to two persons of equal power opposing each other in opening a gate. By a pinion D, or pulley on the solid centre of the globe, motion could be communicated to machinery; and a modified engine of this class was employed in the printing establishment of Messrs. Chambers of Edinburgh.*

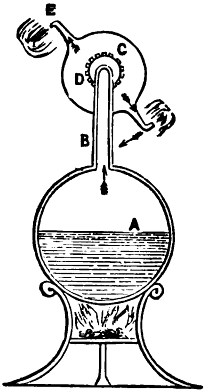

Fig. 3.
Ancient Rotatory Engine.

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* Before noticing the altar-engines, it may be interesting to state, that the properties of the atmosphere and of a vacuum were discussed by Hero as they now are; that various figures illustrate the motive power between water and air pressure; that Figs. 9, 49, and 54 show the power of compressed air; Fig. 27, an effective fire-extinguishing engine with two bronze cylinders, "bored in a lathe to fit pistons," and each piston connected to one end of a beam vibrating on its centre, as in modern engines; Figs. 11, 37, 38, 60, and 70, the power of hot air, or hot air with steam; Fig. 57, a syringe; Figs. 4, 33, 68, and 78, the screw-press, rack and pinion, bevel-gear, pulleys, and counterweights; Figs. 74 and 75, cylindrical boilers with inner concentric hot-air chambers or fire-places (in which fire-pan and grate could be let down, as in Moses's altar of burnt offerings), and tubes for admitting air, for blowing the fire by hot air, for blowing a trumpet, and for whistling like a blackbird; Fig. 76, an organ-blowing cylinder, with slide-valves to each pipe, worked by a bell-crank motion similar to the rocking-shaft valve motion of locomotives, or Ericsson's caloric engine; and Fig. 77, a windmill working an organ-blowing cylinder.

Altar-Engines.—Hero's description of these engines shows a clear knowledge how to apply the powers of steam or hot air to raise fluids. His eleventh and sixtieth inventions, entitled "Libations at an altar by fire," and "Libations poured on an altar, and a serpent made to hiss, by fire," display both scientific and practical skill; for on a large scale both libation-engines would be quite capable of exerting immense lifting power. One example will therefore be given, as both morally and practically instructive on this point.

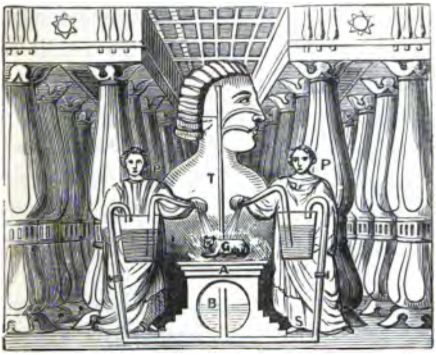

Fig. 4.—Double-acting Idolatrous Engine.

"I am all that has been, or will be; and no mortal has ever lifted my veil."—Isus.

Let Fig. 4 represent Isus in his splendid temple, with the altar A,* sacrifice C, and the attendant altar guardians.

In the most elaborate of these designs, hot-air power is a leading feature, aided by steam to increase its effect.

* In the British Museum, Egyp. Gal., No. 135, is a small altar of libations, with a central tank (or boiler like Brindley's stone ones), and in the bottom are three holes, as if for pipes, arranged after Hero's design. In the Egypt Room, cases 24-5, is a libation-vase with a large strap-like oval hole through it, and which divides it at that part into two separate vessels, but forming one vessel only at the top and bottom. This vase could be easily bound to any person or object, and its tubular orifice convey hot air or steam into it, whilst another similar tube might lead from the top—now broken off—to a cup in the priest's hand.

Part of it is sectional, to show the secret engine clearly. B, the boiler from which the steam passes by the pipes S S into the wine-cylinders to force their contents out by the pipes along the priest's arms, similar to Porta's, Worcester's, Morland's, Papin's, and Savary's and other similar water-raising engines. The wine-pipes terminate in cups held by the priests, and a third steam-pipe, T, passes from the boiler to the idol's head, with branches to the mouth, or nose, or both. With convenient stop-cocks, and all concealed from view, this mechanism gave great power of deception.

Suppose, for instance, that the priestly exhortations were ended, and the worshippers expected the public sanction of the idol, hot air or steam admitted to the head would give the oracular response on any concealed musical or other mechanism there, whilst the steam would escape like breathing. In like manner with the sacrifice, steam or hot air admitted to the wine-cylinders would cause it to flow out into the cups, as if miraculously obtained. Since it better accounts for various historic records of scenes at idolatrous worship unaccountable to the witnesses, we have merely altered Hero's original "serpent's head hissing" for a man's head, as a statue, on which the heat of an eastern sun would generate steam of available force from any water concealed in it.*

Air would also produce similar effects when heated. By admitting it at one opening, and its expansion by heat shutting that entrance and opening another for escape, the heat of the sun would give sufficient power to emit sounds.

Philostratus states that sounds proceeded from Memnon like a stringed instrument when the sun shone. Pausanias compares them to snapping the strings of a harp, and Strabo mentions his having heard similar sounds thus :—

"Memnon's broken image sounding,
Tuneful 'midst desolation still."

---

* Serpents were formerly venerated as idols.

Closed from the air, a little water confined in any exposed part of this celebrated idol would produce these sounds again and again, "when the sun shone."

De Caus's Sun Fountains, 1612.—The recorded movements of idols when the sun rose, and of the sounds proceeding from them, led the mechanics of the seventeenth century to imitate them by various ingenious arrangements of mechanical music. Amongst these was De Caus, and, as showing the power of the sun on confined water, we give in this place two of his illustrations of ancient sun fountains.

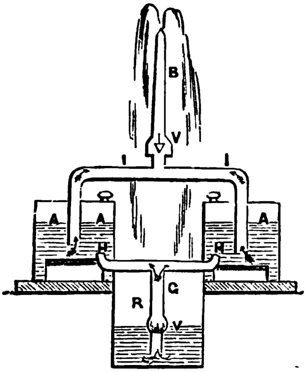

Fig. 5.—Sun Fountain.

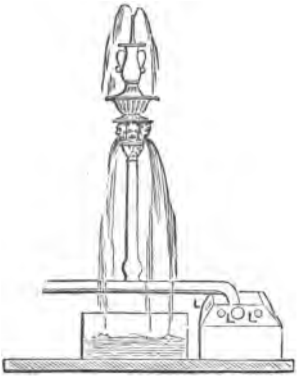

Fig. 6.—Lensed Sun Fountain.

Fig. 5 is a sectional view of two copper vessels (four were used) A A, filled with water at H H by atmospheric pressure from the well R. The heat of the sun expands the water in A A and forces it up the pipe I B about five or six feet. To increase the effect of the sun, "burning-lenses," L L L, Fig. 6, were introduced, which raised the water much higher than before. The acting force is steam and air compressed in A A until their power exceeds that of the atmosphere acting on the water in R. With a fire instead of the sun, these would have been useful water-raising engines.

There exist, therefore, no good grounds to discredit the testimony of those who describe scenes often deemed fabulous, since our own "wizards" prove how readily the eye fails to detect artifices confessedly practised. Neither need it excite much surprise that nations had faith in a mythology at once sublime and awe-inspiring, and commanding the services of such clever priests and skilful mechanicians. For a good-sized engine was not only equal to gently pouring out wine, but might in one instant be made to eject the steam or water amongst or against any refractory worshippers, as is supposed was done by Archimedes to defend Syracuse.

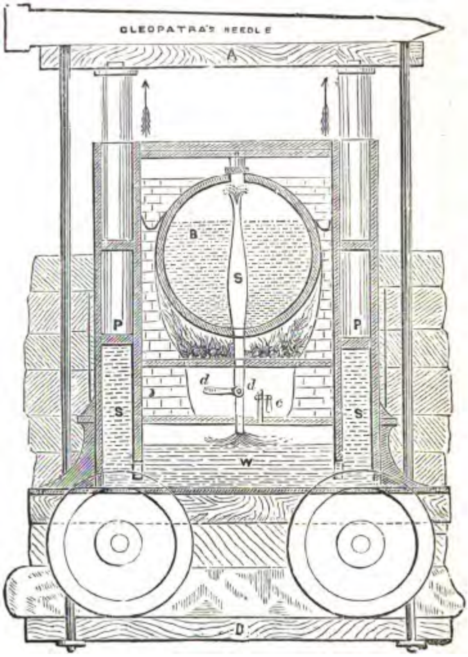

Fig. 7.—Single-acting Altar-engine as a Crane.

Altar-Engines as Cranes.—Fig. 7 is a crane nearly identical in its form to Hero's eleventh invention (which is a water-raising engine), but mounted on wheels for conveying materials from place to place. B the boiler, S the steam-pipe, W the water-cistern, and S S the water-elevation pipes. This is the altar hot-air engine as shown by Hero. Now if we place a piston P in each tube S, and connect them together at the top by a platform A, from which another platform D is suspended, we have evidently a crane of great power and simplicity; for as air or steam admitted into the cistern forces the water up the pipes, so would any weight be lifted within the limit of the crane-power.

By opening the small cock *c*, weights could also be lowered by allowing the force to escape more or less rapidly as required; in short, raise or lower weights with as much delicacy as is now done by any crane.

On the lowest platform a block or load could be readily placed from the ground, then raised one lift from the crane, and blocked up for another lift, and so on until the required height was gained.

Fig. 8 is a six-wheeled steam-crane on the plan of the wine-libation engine, Fig. 7, but with the steam-pipes from the top of the boiler, as they are not required to be concealed as in the altar-engine. The same letters apply as in Fig. 7. By this means, still greater delicacy in raising blocks to any angle is obtained, by admitting steam to or from each separate syphon-shaped cylinder as required. With such cranes, the most ponderous monoliths, even the great sphinx itself, would be readily handled or removed.*

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* These cranes were engraved before seeing the sculptured outline of the 4 and 6-wheeled besieging engines of the Assyrians in the Nimroud Gallery of the British Museum, which embody a similar idea of power to work the highly inclined battering, or rather excavating, arms, and of portability by wheels. Since such engines were employed to destroy edifices, by a sight modification they could also aid in erecting them, although it is the usual opinion that inclined planes, rollers, and man-power were the chief lifting resources of the ancients. This

The use of steam, for religious and other professional purposes, appears to have made its power a secret known only to the initiated, until the republication of Hero's treatise, in 1547, set in motion that mental power which, step by step, has made the steam-engine what it is.

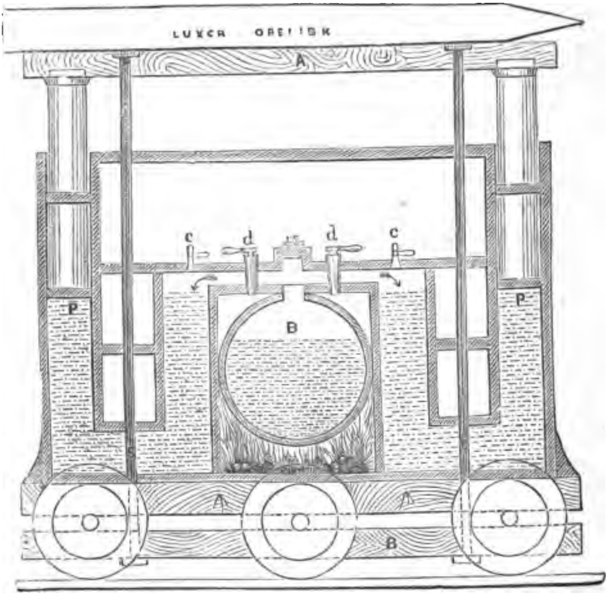

Fig. 8.—Double-acting Altar-engine as a Crane.

opinion is, however, scarcely consistent with their known scientific and practical resources.

For special occasions, as in Mr. Layard's case, inclined planes or other expedients might be adopted, and from their contrast to the ordinary means be similarly delineated, yet as little represent the mechanical resources of the ancients as those employed in removing the Nimroud sculptures did those of Great Britain.

The efforts of commentators to explain down to their own ideal of ancient knowledge the plainest references to skilled productions by Moses. Homer, and others, ill accord with the results of discovery.

Anthemius, 530.—In revenge for having been baffled in a wordy dispute by Zeno the orator, this architect of Justinian conveyed steam, by elastic pipes, below the floor of Zeno's house, and so alarmed the orator that he yielded to a rival who shook his house and the "earth as with the trident of Neptune." It is thus clear that Zeno had no knowledge of steam power, so familiar to his professional opponent.

Gerbert, 1125.—This learned priest appears to have applied one of Hero's plans to an organ at Rheims, in which the air, escaping by the force of heated water, produced musical tones in combination with water.

Alberti, 1412.—The knowledge of the extreme force of steam again appears professionally by Alberti comparing it, when generated from water in the cavities of limestones, as bursting them with great noise, and blowing up the kiln with irresistible power.

De Garay, 1543.—Spain being in the meridian of her power about this time, the transporting of her armies across the ocean became an object of great importance, when De Garay, one of her naval captains, proposed to propel ships by steam. The Romans transported Claudius Caudex's army into Sicily by paddle-wheel boats worked by oxen; and in 1472, Valturius describes two paddle-wheel galleys. The one had five wheels on each side, and each opposite pair connected together by a cranked axle. These cranks were again connected together, that the motion of the paddle-wheels might be simultaneous. The other boat had only one paddle-wheel on each side, fixed on a cranked axle.

Acquainted, probably, with this or earlier Homeric ideas or modes of moving ships, and ambitious to emulate the Romans, De Garay selected steam as his auxiliary. His plan was kept secret, but a steam-boiler was on board, and the paddle-wheels were seen to propel the vessel. It might be done by a rotatory steam-wheel, like Hero's, on the paddle-shaft, or by a steam-jet driving a central wheel, as in Fig. 9, or by a steam-jet, issuing at the stern, against the resisting water, but below its surface. The result of a trial at Barcelona, before the Spanish court, was that a vessel of 200 tons burden was propelled about three miles an hour—no mean performance then—and now interesting from the progress of steam navigation. De Garay's success was honoured by the court; but his invention was neglected.

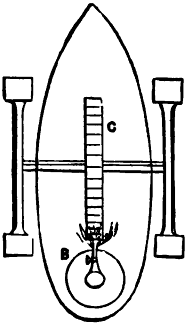

Fig. 9.
De Garay's Steamboat, 1543.

The republication of Hero's treatise at Bologna, in 1547, and at several other places, led many eminent men to suggest various modes of usefully employing steam and hot air, a few of which will be noticed.

About 1548, Vitruvius refers to the steam from an æolipile as wind produced by heat; and Philibert de l'Orme proposed an æolipile to cure smoky chimneys.

Cardan, 1557.—The force of steam, and the rapid vacuum produced by its condensation, are both ably treated by Cardan, who also invented the smoke-jack, as still made, to illustrate the power of hot air. Possessing great scientific and superstitious knowledge, his life presents a singular blending of these together; as was also partially displayed in England by the Marquis of Worcester and other inventors.

Bressen, 1569.—An anonymous pamphlet, published at this time, on the expansive force of steam, is attributed to the pen of this celebrated mathematician and reputed author of a collection of machines, but published in 1578, after his death.

Matthesius, 1571.—In a sermon Matthesius illustrated the great effects produced by small things, by reference to the great power produced by heat from a small quantity of water.

In 1577, a rotatory steam-engine, Fig. 10, was employed to turn a roasting-spit, as a great and *clean* improvement upon the dog, previously employed to do so, but not always proof against "pawing" the savoury temptation beside him.

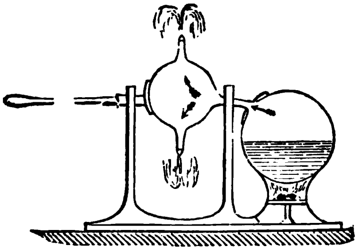
Fig. 10.—Roasting Engine, 1577.

In 1578, an English military writer, and in 1587, Paucerollus, both refer to paddle-wheel vessels as then in use.

Ramelli, 1588.—At this time another collection of machines was published by this experienced engineer, which, along with that of Bressen, greatly promoted subsequent improvements in steam and other machinery.

Platte, 1594.—Sir H. Platte describes steam as "water attenuated by fire into air," which, by its emission from a whirling æolipile, made of copper, blows a fire strongly.

He also suggested the collection of steam from domestic operations, and conveying it by pipes to force the growth of plants in a house near the kitchen,

Porta, 1601—1609.—Porta's plan of showing the relative volume and force of steam in raising water, was an ingenious one for his time.

The neck of the boiler B, Fig. 11, rises above the water in the vessel A, so that the steam generated in B may force the water out of A up the pipe D. The pressure of the steam was ascertained by weights on the valve C, and its relative volume by the ratio of the quantity of water forced out of A to that evaporated in B to force it out. Although not an accurate plan, still it shows a clear notion of obtaining that knowledge of steam which has so much engaged the attention of modern philosophers. It was given by Porta as an improvement on Hero's fountain, Fig. 2. The popular magic lantern is Porta's invention.

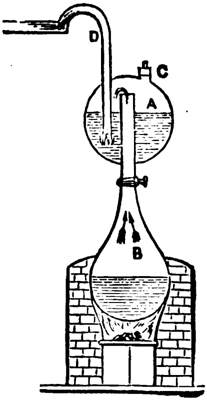

Fig. 11.
Porta's Engine, 1606.

Rivault, 1603.—Rivault shows a knowledge of the great force of steam, by his comparing it as equal to burst a bomb partially filled with water and placed on a fire, as in Fig. 12. The abutment, or point of resistance to the escaping steam, being in a line opposite to the fracture, the burst shell would be carried in that direction, as indicated by the arrow. Likewise, in any explosion of steam, the boiler would be forced in a line opposite to the fracture.

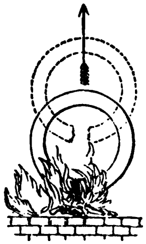

Fig. 12.—Rivault on the Force of Steam, 1603.

S. De Caus, 1612—1615.—There appear to have been two De Caus's—a Solomon, the eminent engineer, and an Isaac, also a steam-engine historian. Solomon describes steam as "water dissolved into air by fire," and its force as "infallibly bursting a copper ball containing water and exposed to heat."

He also discusses the evaporation of water by heat, and the condensation of such vapour by cold to its original volume of water again.

Fig. 13 shows his plan of raising water. As the steam is generated it forces the water below it at B up the pipe C. The pressure of the steam is regulated by the valve D, at which also the boiler was filled. For raising water, his plan is inferior to Porta's in economy, since the hot water is expelled from the boiler, causing a loss of both time and heat in generating steam again. Porta's, on the contrary, forces cold water from a separate vessel, and retains the hot water for steam, a difference greater than, yet not much dissimilar to, Newcomen's condensing in the cylinder, and Watt's condensing in a separate cylinder.*

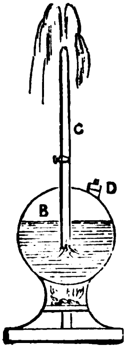

Fig. 13.
De Caus's Engine, 1612.

Ramsay, 1618.—In 1618, David Ramsay obtained a patent for a new engine to plough without horses or oxen, to raise water, and propel ships without sails; also, in 1630, to raise water by fire from deep pits, move ships against wind or tide, and to fertilise the earth.

Branca, 1629.—In his mechanical treatise, this distinguished physician describes a rotatory steam-engine he used for grinding his drugs. He gives the top of the boiler the form of a man's head with a pipe in his mouth, blowing a jet of steam against the arms of a wheel, Fig. 14, to cause it to rotate on its axis, and by the pinion give motion to the drug machinery.

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* De Caus's sun-fountains are given, Figs. 5 and 6, as illustrating the effect of the sun on water in idols.

A modification of this plan was tried at the Surrey Docks, with a wheel of 11½ feet diameter, making 500 revolutions per minute. But the consumption of steam for an equal duty being greater with the rotatory than with a piston engine, led to its disuse.

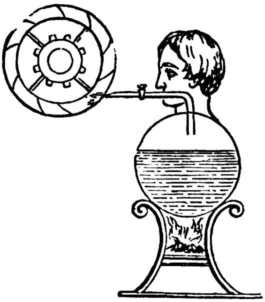


Fig. 14.—Branca's Engine, 1629.

Branca also describes a hot-air rotatory engine, driven by the heat and smoke collected from a smith's forge; whereby to aid the smith in his operations; but all these engines he gives as the invention of others and not his own.

Drebbel, 1630.—The sounds emitted by the idols of the ancients are said to have been successfully imitated by Drebbel; introducing a little moisture with the air, their mutual expansion by the heat of the sun produced a "soft and pleasant harmony." This is closely following some of Hero's singing-bird illustrations, where the expansion of air by heat performs a chief part, aided by steam when required.

In 1632, amongst several other inventions, Thomas Grant included moving ships without sails; and in 1640 Edward Ford also proposed to move ships against wind or tide by some great power not clearly defined.

Wilkins, 1648.—In a contest of wit with the Duchess of Newcastle, Bishop Wilkins, besides other ingenuities, suggested the possibility of flying by "high pressure" steam moving large wings, which has been more than once attempted in modern times.

Marquis of Worcester, 1651—1663.—On the fall of Charles I. in 1648-9, the Marquis fled to the Continent, where he remained until 1656, when he returned secretly to London for Charles II., but was taken and imprisoned in the Tower. At the time of his exile, Hero's treatise had gone through five editions, besides the treatises of others already referred to; and when so much attention was directed to motive engines, it was likely to arrest the noble exile's notice when abroad. It is probable that from these sources most of his ideas originated, as afterwards given in his letter of 1651 to Hartlib, and in his hundred inventions of 1656.

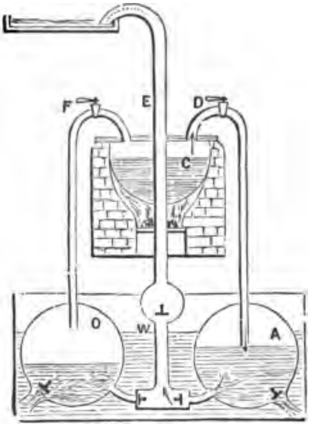


Fig. 15.—Worcester's Engine, 1656.

In his writings and prayers, he thanked God for showing him "so great a secret of nature, beneficial to all mankind," yet he studiously withheld from mankind the construction of his "semi-omnipotent," power, leaving it to be considered as a steam-engine.

When a political prisoner in the Tower of London, this celebrated nobleman—after the example, but without the clear illustrations, of Hero—drew up "The Century of Inventions." Of these the 68th refers to the steam-engine "as an admirable, most forcible way to drive up water by fire, which hath no boundes if the vessels be strong enough." He also compares the force of steam to the bursting of a cannon, evidently then, as it still is, a popular expression for a great force. No drawings or description of his engine have been found in this country; but, in 1656, the Duke of Tuscany saw an engine lifting water 40 ft. high, at Vauxhall.

To the perplexity of readers, different authors have differently embodied the Marquis's description. Stuart and Galloway show a double De Caus engine, whilst Millington and Tredgold sketch a double Porta's engine, as in Fig. 15, where the steam from the boiler C passes down the pipe D, to expel the water from A, whilst O is filling with water from the well W. The valves all open only one way, as in the sun-fountain. The cock in D is then shut and F opened, that the steam may expel the water from O up the central pipe E, whilst it is refilling again, and so on alternately to keep "one forcing whilst the other is filling," agreeably to the text.

The Marquis also proposed to move ships by paddle-wheels against the wind or stream; but it is much to be regretted that he left no tangible evidence of his designs, such as is done by those preceding him in their illustrated works.

Otto Guericke, 1654.—This able man records some valuable experiments which illustrate the pressure of air in raising water or in depressing a piston. In Fig. 16, the pressure of the air on the water in C is forcing it about 30 ft. up the pipe A, previously exhausted of air, into the receiver E. If the vacuum had been perfect it would, as previously explained, have risen nearly 34 ft. high.

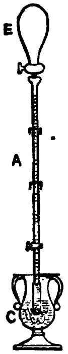


Fig. 16.
Atmosphere raising water.

Fig. 17 shows the air pressing down the piston P (17 in. diameter) in the cylinder C, previously exhausted of air, into E, whilst a number of men are in vain exerting themselves to prevent its descent. Fig. 18 shows the pressure exerted balanced in a scale by 2,686 lbs. The area of a 17-in. piston being nearly 227 square in., gives 11·8 lbs. per square in., or nearly the same as is obtained in a Watt's condenser. If the vacuum had been perfect the pressure would have been $14\frac{3}{4}$ lbs. per square in.

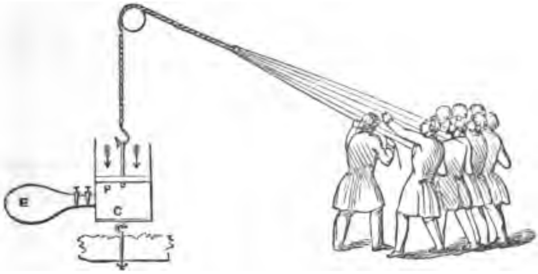


Fig. 17.—Man-power of Atmosphere.

Kircher, 1656.—Kircher's illustration of Porta's plan might be made a pretty little fountain, by receiving the falling water in a cistern fitted round the stem B, and raised by atmospheric pressure to refill C again, as Fig. 19. He also suggested an improvement on Branca's engine, by having a blast of steam on each side of the wheel at the same time; and his models are highly spoken of as the workmanship of a mechanic named George De Sepi.

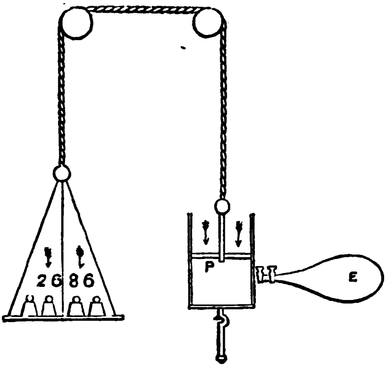


Fig. 18.—Weight-power of Atmosphere.

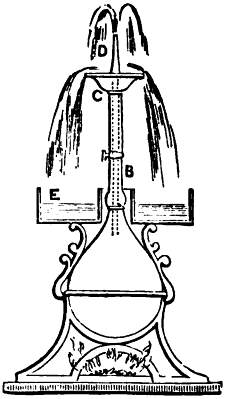


Fig. 19.—Kircher's Engine.

Jack of Hilton, 1658.—" Jack " is described as an artistic ælopile, resembling the human figure, with his right hand on his head, and his left hand " on pego," to blow the fire in Hilton Hall, whilst the Lord of Essington drove a goose three times round that fire before it was roasted for the Lord of Hilton, celebrated in Godiva procession annals.

Sir S. Morland, 1670—1685.—This distinguished mechanic wrote an essay (now in the British Museum), on the " Weight and Measure of Water elevated by Machines." His plan was by alternately filling and emptying two or more cylinders 30 times (or strokes) per minute. The duty he estimated by the weight raised in a given time, as is still done in this country. No drawings of his engine have come under our notice, but Fig. 20 embodies the description given of one with two cylinders. On steam passing from the boiler B to the cylinder C, it expels the water up the central pipe E, while A is filling with water from the well W, to be emptied

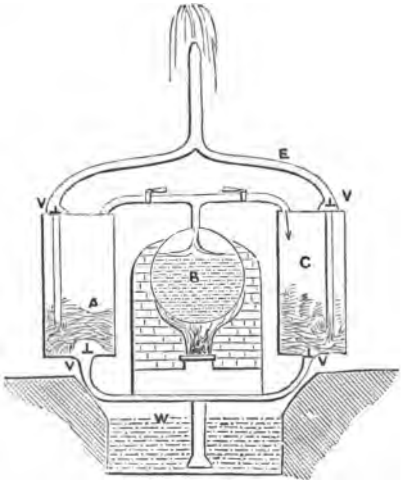


Fig. 20.—Morland's Engine, 1680.

in like manner whilst C is filling, and so on alternately. The relative volume of steam to water he gives as about 2,000, and its force as capable of "splitting a cannon;" but being regulated by "statics and science to *measure, weight,* and *balance*," it bears its load peaceably like a good horse, and becomes of great use to mankind.

He gives the following proportions of cylinders, and the weight of water they would raise each stroke. We have added the height in inches of the water raised equal to the diameter of the respective cylinders.

	CYLINDERS.		WATER RAISED EACH STROKE.	
No.	Diam.	Length.	lbs.	Height in each Cylinder Inches.
1	1	2	15	3·7
1	2	4	120	7·4
1	3	6	405	10·0
1	4	8	960	14·7
1	5	10	1875	18·3
1	6	12	3240	22·0
2	6	12	6480	22·10

and so on to 90 cylinders, each lifting 3,240 lbs., or 291,600 lbs. of water raised a considerable height per stroke. There can, therefore, be no doubt of Morland's clear appreciation of the nature of steam, and the method of estimating its performances. In 1675, he raised water from the Thames 60 ft. above the top of Windsor Castle, at the rate of 60 barrels per hour, by eight men, which gave so much satisfaction, that in 1681 the king presented him with his medallion portrait set in diamonds.

In 1678 Bushnel proposed to propel ships by oars bound together, and the rope ends fastened to the capstan, to be wound off and on alternately for each stroke of the oars, as afterwards tried by Fitch in 1788 with steam-power.

Hautefeuille, 1678.—This learned abbé and mechanist gave designs of engines for using heat, steam, gunpowder, and alcoholic vapour as motive agents. One plan was by direct pressure of steam or hot air on water; another by condensing the steam or vapour below the piston, to produce a vacuum for the atmosphere to force down the piston, as in Fig. 70; and a third was by exploding gunpowder on alternate sides of a piston.

With steam, Savary and Newcomen effected the first and second; but the third has not yet proceeded beyond experiment A recent trial of gunpowder as a motive power, at Swindon Station, by James Squires—an ingenious mechanic and electric experimenter there—indicated that, as in shooting, the *débris* of the powder speedily choked up the moving parts, and arrested the engine. It was tried by fitting a separate powder-chest at each end of a small cylinder boring engine, and the powder was regularly admitted by a valve, and exploded by galvanic agency. The action was impulsive and not sustained, which, with the deposit from the gunpowder, discouraged further trials.

In 1681 the Prince Palatine Robert's boat, propelled by revolving oars on the Thames, beat the king's 16-oar boat by a long distance. Papin was present at this trial. In 1682, a horse paddle-wheel boat was employed at Chatham for towing ships.

Sir I. Newton, 1680.—In his "Explanation of the ,Newtonian Philosophy," Sir Isaac Newton shows the elastic force of steam, by its locomotive capabilities, as Fig. 21, where the globular boiler, with its steam-jet pipe and cock, is mounted "upon little wheels, so as to move easily upon a horizontal plane; and if the hole be opened, the vapours will rush out violently one way, and the

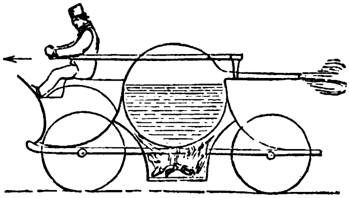


Fig. 21.—Sir I. Newton's Locomotive, 1688.

wheels and the ball at the same time will be carried the contrary way." This is the first idea of steam locomotion we have met with.

The principle of producing locomotion by the velocity of one fluid acting against a fluid comparatively at rest has formed the subject of a patent by Allen in 1724, Rumsey in 1788, and Gordon in 1845. It was also the plan of Matthesius's roasting engine, Hero's rotatory engine, and various other inventions since that time.

Papin, 1680—1707.—This eminent physician and engineer proposed to apply steam to various purposes. Amongst others to dissolve bones, to throw bombs, to drive machinery, to propel ships, and to raise water. In his celebrated "Steam Digester" for dissolving bones into useful food, he employed steam of a temperature equal to melt lead, or about 612°. This indicates a pressure of about 1,400 lbs. per square inch, which would propel either balls or bombs with very great force; for Perkins's celebrated steam-gun of 1838-9 only used steam of 410° Fah., or 450 lbs. pressure per square inch. To regulate the force of the steam in the digester, he invented and employed the steelyard safety-valve *c*, Fig. 22. The lever *c* is jointed at one end to the valve seat, and the fulcrum is jointed centrally with the safety-valve on which it rests. The weight *a* presses the valve down by the fulcrum with more or less force proportioned to its distance from the centre of the valve. This valuable invention is still used in steam boilers in its original plan, although various similarly loaded levers with shifting weights are shown in Hero's ancient designs.

In 1687, at Marbourg, Papin constructed an atmospheric engine for raising water to drive a wheel, which also worked the air-pumps used for producing a vacuum in the long mine pipes, below the piston, as in Otto Guericke's experiments.

To render the action continuous, two cylinders were joined together by a two-way cock, which alternately opened each cylinder with the air-pump and the atmosphere. Each piston was connected by a rope to a shaft to give it motion, but the ropes were wound round in contrary directions, so that as one was raised the other was depressed; an arrangement adopted afterwards by Leupold for high-pressure steam.

Like that of the late promoters of the atmospheric railway, Papin's difficulty arose from the slowly obtained vacuum and leakages, which he failed to overcome.

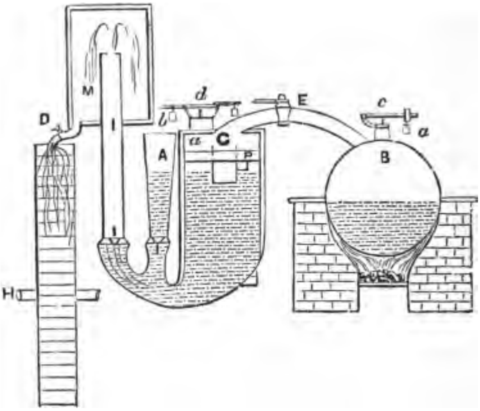


Fig. 22.—Papin's Engine, 1704.

His numerous experiments showed him the advantage of a good vacuum below the piston, which he sought to obtain in various ways; amongst others, by the explosion of gunpowder in the cylinder. This he abandoned as dangerous, and proposed to raise the piston by the steam, and then to condense it, that the air might depress the piston against a vacuum. He did not carry this out, but it was successfully done by Newcomen. Savary's success in England led the Elector of Saxony to recommend Papin to abandon his own superior proposal, and try Savary's plan. Fig. 22 is an outline of the result, which Papin calls the Elector's Engine.

Steam from the copper boiler B passes by E to the cylinder C and presses down the floating piston P, to force the water up the pipe I into the cistern M. The cylinder safety-valve was then opened to admit the steam to escape, and the water from the mine, aided by the air vessel A, refilled the cistern. For driving machinery a water-wheel was added, and the cistern M made air-tight. The outlet pipe D being smaller than the inlet pipe I, the air acting with the water was compressed and aided in keeping up a uniform force to turn the wheel H and produce a regular rotation. Even down to Smeaton's and Newcomen's time, this was an approved mode of rotation when available.

For steam-ships Papin employed two or more cylinders, A, B, Fig. 23, having racks jointed to the piston rods, and arranged to gear alternately into the central pinion P on the paddle-shaft, and produce rotation. Several modifications of this plan were tried before the crank came into general use.

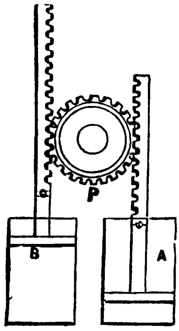


Fig. 23.—Papin's Marine Engine.

Papin first systematically tried to save fuel by improved boilers. One form was bent like a syphon, with the fire in the short end, and the draught down through the fire, whilst the cylinder was fixed on the long end, so that the heat acted on it in its passage to the chimney. The fire-bars were, however, so quickly destroyed by the intense heat, that it was called the "little volcano," and probably led Papin to recommend hot air for reducing mineral ores, as successfully done by Neilson in the present century.

Another boiler was 8 ft. by 5 ft., with a tubular flue 24 ft. long by 10 in. square, bent so as to pass four times through the water. This gives a heating surface of about 80 square ft., and led to a saving of about 75 per cent. of the fuel then used for ordinary boilers.

Although an account of this boiler, and other novel machines by Papin, was published in 1695 by Cassell, yet it appears not to have been known to Savary or Newcomen, since they used inferior boilers for their engines.

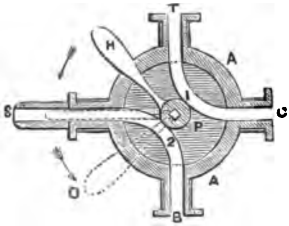


Fig. 24.—Papin's Two-way Cock.

Fig. 24 is a sectional view of the useful and ingenious two-way cock of Papin, but usually called a four-way cock from the four external openings in the outside socket A A. The central plug P is fitted steam-tight into the socket A A, like an ordinary cock-plug, but has two passages 1, 2, through it, which alternately connect each adjoining pair of external openings, or shuts them all, as the plug is moved by the handle H one-eighth or one-quarter turn.

For a double-acting steam engine the passage S B leads from the boiler below the piston, and the passage T C from the top of the piston to the condenser, or to the atmosphere in high-pressure engines. By moving the handle H to S the passages are all shut; but when moved on to O, the boiler is connected by S T to the top of the piston, and the condenser by C B below the piston.

To equalise its wear, Bramah improved its form, and made the plug turn quite round within the socket.

It is thus seen that several important inventions and valuable suggestions, since reduced to practice, are due to Papin.

In 1699 boats propelled by revolving oars were tried both at Marseilles and at Havre, by M. Daguet, which were favourably spoken of.

Amonton's Hot-air Rotatory Engine, 1699.—This was an ingeniously arranged box-wheel, 12 ft. diameter, fitted with thirty-six air-tight cells, of which the twelve inner ones had valves opening upward only. In the lowest four of these valved cells were 750 lbs. of water, which was forced up one side by hot air, that its unbalanced gravity might give a downward motion to the wheel, and produce rotation.

The action was by a tube conveying the hot air from each outer cell to each third lower water-cell, to force its contents up through the valve in rotating, and as the wheel revolved its lowest edge passed through water to condense the rarified air again. The fire was placed in a confined channel, to act directly on the outer air-cells, resembling the position of a breastwater wheel; but instead of the downward water-flow, there was an upward hot-air action, yet both produce a similar rotation downwards by the gravity of water.

The heat given out to the water by the hot air was thus lost, which in Ericsson's hot-air engine is mostly recovered by exhausting it through wire gauze, and passing the cold air through this heated gauze to re-absorb the heat from it.

Savary, 1698—1702.—The great energy displayed by Savary in improving and introducing steam-engines added much to their popularity in England. His first engines were nearly the same as those already described, with the addition of cold water poured over the cylinder to produce a more rapid vacuum in it, but which had the bad effect of cooling it each stoke. He next improved the steam-admission valves, the mode of opening it, and his boilers.

In Fig. 25 the two boilers are connected together by the pipe 3, and have gauge-cocks C C to ascertain the relative height of the water in them. The largest boiler A is filled from the water-tank T, and the small boiler is supplied with steam and hot water from A. The steam-pipes 1 2 from B convey the steam alternately from the vessels E V, to expel the water in them up the central pipe L, as in Morland's engines. When one of these, as E, has been emptied, the cock F is opened by the handle G, and cold water poured over the vessel to condense the steam in it, and in like manner with V. The handle H conveniently regulates the steam-valves, and G the injection-cocks. One of Papin's safety-valves, D, regulated the force of the steam in the boilers.

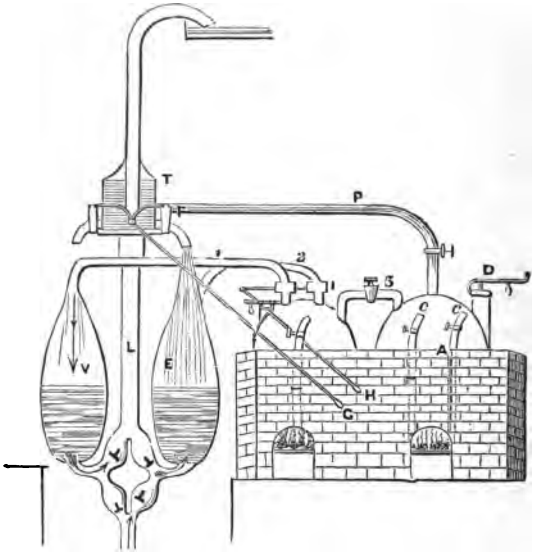


Fig. 25.—Savary's Engine, 1702.

It is related that Savary accidentally discovered the force and condensation of steam from a wine-flask, not quite empty, being thrown on a fire and producing steam, when he took it off the fire and immersed its mouth below cold water, which condensed the steam, and filled the flask by atmospheric pressure.

The labours of Worcester, Morland, and others in England had so publicly shown the capabilities of steam, that in all probability Savary was fully aware of its force; but such an incident might suggest the mode of condensation he adopted, and which, applied internally, still exists.

Savary states:—"My engine raises a full bore of water sixty or seventy feet high, and, if strong enough, I would raise you water five hundred or a thousand feet high."

Only in the improved boiler and valve arrangements do Savary's engines exceed the idolatrous one, since the action of both is similar in passing from the boiler to two separate vessels, and expelling their contents out by other pipes.

Savary also proposed to propel ships by paddle-wheels worked by the capstan and suitable connecting ropes, which the Lords of the Admiralty referred to their surveyor, Mr. Dummer, who, like Sir W. Symonds in 1837, on Ericsson's screw propeller, reported against Savary. Still unsatisfied, he persevered, until one of the commissioners thus faithfully expressed the sentiments of many in authority besides Government officials: "What business have interloping people, that have no concern with us, to pretend to contrive or invent anything for us?"

Newcomen's Atmospheric Engine, 1705—1720.—The exertions of Papin and Savary to bring the steam-engine into general use for draining mines stimulated others on in the same path, and amongst these Newcomen, a country blacksmith, honourably distinguished himself by his decided improvements on the steam-engine. Hitherto the air had only been used to fill the water-vessels, but on the principle, so clearly laid down by Otto Guericke, Newcomen employed the air to perform the principal duty, and steam only as an auxiliary. He also introduced the beam or balance-lever, D E, Fig. 26, freely suspended on its centre B. The piston P was kept tight by a little water on its upper surface from the tank T, and was attached by a rod and chain to D, whilst a common lifting-pump M, leading to the mine, was attached to the end E. The cylinder was placed over the boiler F, and as the steam raised the piston, the counterpoise weight I lowered the pump-rod and bucket down through the water. The injection-cock L is then opened, and water admitted to condense the steam in the cylinder. The air passed out by V, and the condensed steam and injection water by the pipe *q*, to the hot well W. Watt's principal improvement consisted in placing his condenser in the position of the hot well, and condensing the steam there in place of in the cylinder. By thus condensing the steam below the piston, Newcomen obtained a good vacuum, and the pressure of the air on the piston forced it and that end of the beam down, whilst the elevation of the other end raised the water from the mine. Steam was therefore only employed to raise the piston, and air to do the duty.

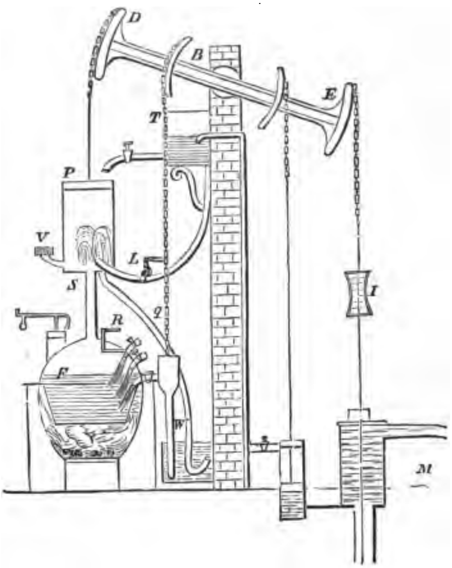


Fig. 26.—Newcomen, 1705—1720.

At first Newcomen adopted Savary's plan of external condensation; but a faulty cylinder having admitted water internally, the condensation was more rapid, with increased effect from the engine. Since that discovery, internal injection has generally, but not always, been adopted.

The various cocks and valves were all opened by hand until Potter, a young lad attending one of the engines, ingeniously connected them to the beam by strings and catches, so as to open them with much regularity. Improved connections succeeded his temporary ones; still to Potter the credit is due of introducing the self-acting hand-gear.

The beam, the pump, internal condensation, and self-action were important additions to the previous steam-engines, earning for Newcomen and his assistants a well-deserved fame.

Desaguliers, 1717, 1718.—This learned doctor gave his preference to Savary's engines, and states that one erected at Petersburg raised 2,520 lbs. of water 40 ft. high per minute; and that another raised water 53 ft. high when making six strokes per minute, but only 35 ft. high when making nine strokes per minute. He also contended that they were more economical and effective than Newcomen's; stating that one of his engines, which cost £80, raised 370 lbs. of water 38 ft. high, while one of Newcomen's, which cost £300, only raised 150 lbs. per minute. Fig. 27 is an outline of Desagulier's engine, with its improved arrangement of boiler-flues; B the boiler, W the water, M the pipe to

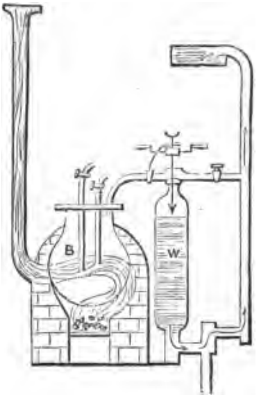


Fig. 27.—Desaguliers, 1717.

the mine. The action is similar to Savary's, but single acting.

Desaguliers' comparative statement merits some notice, since there was a constant loss of heat and time from Newcomen's chilled cylinders, amounting to about thirty per cent. of the whole steam generated. This source of loss would be little felt in Desaguliers', since water only slowly absorbs heat downwards. The following experiment, made by Goldsworthy Gurney, Esq., in September, 1850, at Westminster, in presence of several engineers, bears on these points, and may be instructive. Steam of 20 lbs. pressure above the atmosphere was alternately admitted in contact with cold water in the boiler-feeder A F, and in contact with air between the steam and cold water. Fig. 28 is a sketch of the boiler and feeder on which the experiment was made. As no machinery was required, the boiler was supplied by water without a pump. The water-feeder, A W S, was connected to the boiler by the pipe B, and to an elevated water-cistern by the pipe D. When it was filled D was shut, and B and C opened, that the steam might pass to the top of the water, and balance upward pressure below in B. The water then descends by its own gravity into the boiler.

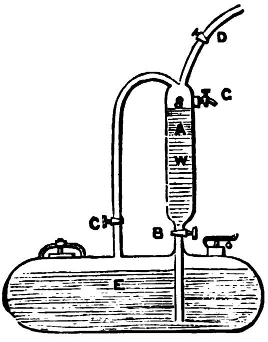


Fig. 28.
Gurney's Experimental Boiler.

When this feeder was partially filled with cold water, then air, then steam, cut off from the boiler at C, the air appeared to slowly absorb heat from the steam; but when the air was expelled at G, and the steam remained in contact with the water, no perceptible absorption of heat from the steam took place. Even after this isolated steam had remained ten or twelve minutes in contact with the cold water, it blew off at G with much force. It was the difficulty of quickly condensing the steam which had done its duty, and not the condensation of the steam forcing the water, which retarded the action of these engines. Internal condensation was more rapid, but entailed the loss from a chilled cylinder each stroke. Besides, the unbroken surface of water rising up slowly against the steam would compress it and increase its force, as it does in the "back pressure" of a locomotive engine. Forcibly injecting broken water like rain amongst steam is a very different process, yet requires eleven times (or more, according to temperature) as much water to condense the steam as to generate it.

Beighton, 1718.—Potter's hand-gear was still further improved by Beighton, so as to open and shut all the valves and cocks with much precision. He also widened the top of the cylinder, to prevent the water on the piston flowing off, and conveyed it by pipes to the boiler, or hot well, as it became hot. The action and arrangements of cylinder, beam, and pump were similar to Newcomen's.

Leupold, 1720.—Leupold recalled attention to high-pressure steam-engines by a very simple yet effective double-acting engine, Fig. 29. The steam generated in B passes alternately by the two-way cock I to the cylinders C C, and raises the pistons connected to two beams which work the lifting-pumps P P, as in Newcomen's plan. A turn of the cock opens a passage for the steam to the atmosphere from one cylinder, and from the boiler to the other cylinder at the same time. The

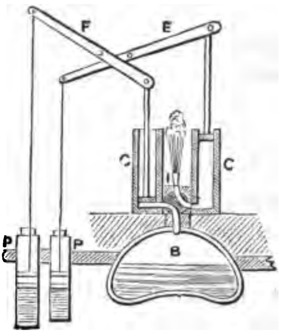


Fig. 29.—Leupold, 1720.

piston end of the beams are heaviest, to balance the weight of the pumps, that the pistons may descend by their own gravity.

This is given by Leupold as an improvement on Papin's atmospheric engine, similarly arranged.

Newcomen raised the water by atmospheric pressure during the downward stroke, but Leupold did so by steam pressure during the upward stroke of the piston; and the simplicity of this engine has rarely been surpassed.

Leupold also proposed an improved form of Amonton's hot-air rotatory, by using tubes instead of valves to connect the water-cells, which were also placed much nearer the periphery of the wheel to give greater effect to the raised water.

In 1724 John Dicken, and in 1729 John Allen, proposed engines to raise water or move mills and ships. Allen's ship-propeller was by a jet of water or other fluid forced through the stern of the vessel below the surface of the water, whose resistance moved the vessel in a contrary direction, as in Sir Isaac Newton's locomotive engine. This idea has been since tried by Fitch, in 1788, with water, and by Mr. Gordon, in 1846, by hot air, on the Thames.

Allen expressed his decided opinion in favour of a steam-propeller of some sort as preferable to paddle-wheels, and more of the nature of a fish-tail propulsion.

To economize fuel with rapid generation of the steam, Allen proposed a fire-box boiler with a spiral flue through the water, and a bellows-blast, to urge the "sluggish vapour" through the tube, as was done in Ericsson's Novelty Locomotive of 1829.

Gensanne, 1730.—By the gravity of water and the impulse of a falling weight, Gensanne made the steam-valve and injection-cock self-acting. On each end of a lever fitted to the water-cistern were water-buckets with a valve in the bottom, and in the cistern were also valves which the buckets opened so that as one bucket was filled and descended by its gravity, the other was emptied and ascended.

The bucket-valve was opened by the gab or fork of a bell-crank lever, which had a weight on its vertical end, and on beginning to ascend, the weight, or "tumbling-bob," was set at liberty, and the fork gave a smart jerk to the ascending levers.

The motion thus obtained was conveyed by another lever and parallel side-rods to open the valve by a gab or fork, and the injection-cock by a slotted lever, at the proper times. This is the first "gab" motion we have met with for working valves.

M. de Moura also constructed another self-acting apparatus of this class, but using a floating copper ball to give a motion outside corresponding to the rise and fall of the water in the receiving cistern.

Jonathan Hulls, 1736.—We have seen that various modes of propelling ships by paddle-wheels or revolving oars had been proposed, using steam or other power to move them. In 1736 Hulls made a vigorous effort to apply a single-acting steam-engine to propel ships. This plan was to produce rotation by ratchet-wheels aided by a weight, whereby to move a central paddle-wheel in deep water, or two poles alternately thrust against the ground by a double-crank axle in shallow water. As the ratchet-motion was much used until superseded by the crank, fly-wheel, and double-acting cylinder, its action will be explained by its modern adaptation to a very useful boring-brace in all confined corners, where a crank-handled brace could not be turned round.

The ratchet-wheel A, Fig. 30, is fixed on the boring-spindle B. The detent or catch C is jointed to the handle D, and kept against the ratchet by the spring E. The handle moves freely round B towards A, without moving it, it, in the direction of the handle of the ratchet teeth, as the detent has no bite; but when moved in the contrary direction, the detent acts directly against the teeth, and carries

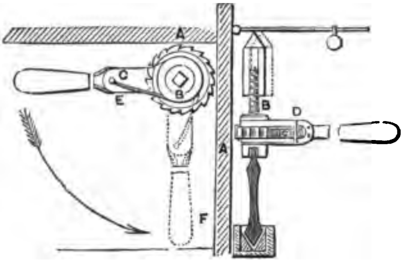


Fig. 30.—Ratchet-motion.

round the ratchet and drill with it about one quarter revolution to F. The handle is then moved back to obtain another bite, and so on consecutively, but losing as much time in stopping as in rotating.

Now two handles with detents moved alternately would produce continuous rotation, and on this principle Hulls, Wasborough and others obtained rotation from a single-acting cylinder. Fig. 31 shows Hulls's plan. A, the steam cylinder, whose piston is connected by a rope to the central pulley on B, and the two end pulleys by other ropes to the loose pulleys 3 4 on the paddle-wheel shaft, on which are fixed the ratchet-wheels 1 2, into which the loose wheel detents fall similar to the ratchet-brace. As the air forces round the piston it moves B round one quarter turn, and with it the paddle-shaft by means of the pulley 4 and ratchet 1

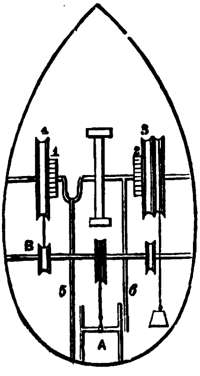


Fig. 31.—Hull's Steam-boat, 1736.

Steam is then admitted to raise the piston, when the weight W works round the pulley 3 and ratchet 2 to keep up the rotation of the paddle-shaft. In shallow water the cranked axle and pole 5 6 were substituted for the paddle-wheel.

1739—1760.—In 1739, Belidor wrote a history of the steam-engine; and in 1741 Payne investigated the density of steam with considerable accuracy.

His spherical balloon-shaped steam-generator rested on its point, and had a vertical rotatory tube, through which water ascended to a horizontal tube above the generator, from whose ends it dropped on the top of the hot generator, to produce spheroidal steam,—a plan again revived.

Experiments made at Newcastle and at Wednesbury are said to have realised the then high evaporation of 8 lbs. of water by 1 lb. of coals.

In 1740 Dr. Hale suggested, and Fitzgerald tried to introduce, air into steam boilers to promote economy, but their bellows were not sufficiently powerful to overcome the resistance of the steam.

In 1845, Mr. Wilkinson, and more recently Dr. Houston, have both patented modifications of this plan of combining air and steam to work an engine.

In 1751, Blake discussed the proportion of cylinders. In 1752, Bernouilli proposed an angular ship propeller on the principle of windmill vanes, to be driven by steam or other power: and in 1758, Emerson investigated the construction of steam-engines. In 1759, Brindley proposed stone and wood boilers, with cast-iron fireplaces and flue-tubes, to prevent loss of heat by external radiation. The bottom was of stone, and the sides and top of wood. Others were of stone, or bricks, cemented together. From the internal fire copper tubes passed through the water to the chimney, as in modern locomotive boilers.

In 1757, as part of an improved plan of Papin's rotation by racks and pinions, Fitzgerald added the fly-wheel, Fig. 32, which now forms a prominent part of fixed engines. To make it effective in regulating the velocity of the engine, it is made with light arms, and a heavy rim, E F, that it may absorb power when the piston is at its greatest velocity, and give out its accumulated centrifugal force to continue the rotation when the piston has no velocity, at each turning point of its stroke. For instance, a stone swung round in a sling acquires a force which propels it beyond the limit which one unaided muscular effort of the hand and arm would have done; so, in like manner, the fly-wheel accumulates a force which continues the motion of the machinery when the piston itself could not do so. C D, the engine beam, A B, the sun and planet motion.

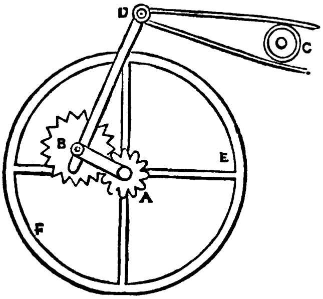


Fig. 32.—Fitzgerald's Fly-wheel, 1757.

In 1760, Genevas proposed a compressed spring propeller for naval locomotion, and a "winged cart" for land locomotion, which has been practically tried more than once during the present century.

Dr. Black, 1762.—The properties of heat and steam were ably investigated by Dr. Black, who propounded the well-known doctrine of latent heat. A modern instance has been discussed of the extent to which the term "latent" is popularly used occurred at a trial of the Midland Railway Company's servants on account of a fatal accident. In answer to counsel, the Company's foreman stated his inability to speak positively to the condition of the piston, as it was "'latent' in the cylinder." On being asked what he meant by "latent," he replied, that if the learned counsel would place his papers inside his hat, on his head, he should say the papers were "latent" in the hat. In this sense the heat in steam may be called "latent," although known to be there in a diffused state.

Blakey, 1756.—Blakey introduced tubular boilers, containing the water in the small tubes, *a*, *a*, *a*, Fig. 33, round which the flame and hot gases passed to the chimney.

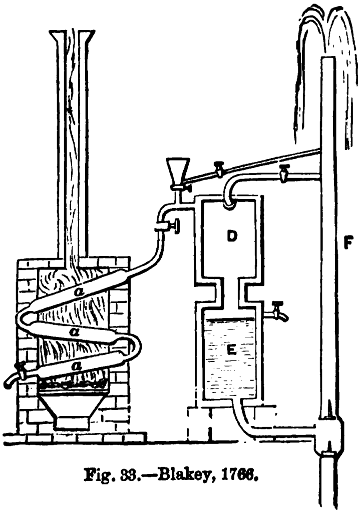


Fig. 33.—Blakey, 1766.

To keep the steam cylinder hot, he added an upper one, D, and employed air or oil as a piston between the water in E and steam in D. The rise and fall of the water in E he ingeniously arranged to open and shut the necessary cocks. The action was by admitting steam into D, which by its pressure on the aërial or oily piston forced the water out of E up the pipe F, and E was filled again from the well, as in Savary's engine.

This tubular idea of boilers has been successfully carried out, sometimes with the water surrounding the tubes as in locomotive boilers, or by having the water in the tubes as in Woolfe's, Gurney's, or Alban's boilers.

Smeaton, 1765.—The careful experiments made by this celebrated engineer reduced the performances of the steam-engine to the weight and measure suggested by Morland.

His experimental engine of one-horse power evaporated 6¼ lbs. of water by 1 lb. of coals, and required nearly 11 times more water for condensing than for generating the steam. It produced the greatest effect with a pressure of about 8 lbs. above the atmosphere. He also determined the relative steaming value of different coals.

This information enabled him to improve the various details of the atmospheric engine and its boiler, which he adapted for portable as well as for fixed duty. One of them erected at Long Benton (Northumberland) in 1772, realised a duty of lifting 112,500 lbs. of water one foot high by 1 lb. of coals, equivalent to 12,600,000 lbs. raised one foot high by 112 lbs. of coal.

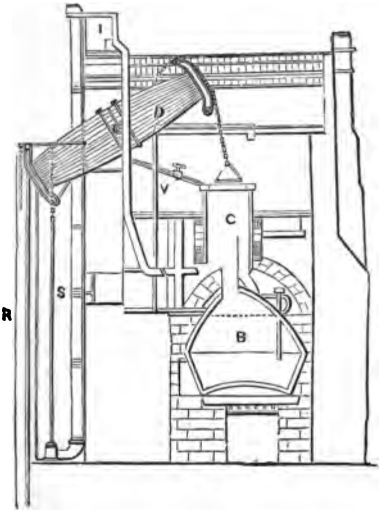


Fig. 34.—Smeaton, 1775.

In 1775 he erected a very large engine at Chacewater, Fig. 34, having a cylinder of 6 feet diameter and 10½ feet stroke. The beam D was made of twenty pieces of timber strongly bolted together. The cylinder C was firmly fixed to the side beams 1, 2, as well as on its end supports on the boiler B. The mine pump was attached to the rod R, and another pump S raised water to the cistern I, from condensation by injection into the cylinder. The rod V worked the steam and injection valves.

The action of the engine was the same as in Newcomen's, air being the principal motive power.

In some of his boilers Smeaton inclosed the fire, and supplied the fuel by a feeding-tube, with the good result of 7·88 lbs. of water evaporated by 1 lb. of coals.

Cugnot, 1763—1771.—In 1763 this French engineer made a model of a steam locomotive, and in 1770 the French government had one constructed at the Paris arsenal, tried in 1771, and then *laid aside.* Through the favour of Monsieur Morin, Director-General of the Conservatoire of Arts and Machinery in Paris, illustrations of this first piston locomotive engine practically tried will be given in the next chapter.

The piston rods worked downwards, as afterwards adopted in Cornwall by Bull, to evade Watt's patent, and now in pendulous engines by various makers.

The inventor became reduced to poverty, and had a small pension from government; but the revolution stopped this, and a humane lady of Brussels relieved him until Napoleon granted him a larger pension than he had lost, but still only about £42 yearly.

Watt, 1762—1800.—This very distinguished mechanical engineer was born at Greenock, in 1730, and died at his residence near Birmingham in 1819, after a long life spent in adding immensely to his country's resources. At Glasgow he became early acquainted with Dr. Robison, who, in 1759, suggested to Watt the application of steam to propel wheeled carriages. Like the earlier idea of Sir Isaac Newton, that steam could be made to produce locomotion, this suggestion was not practically followed up. The value of Britain's mineral produce rendered the application of steam to clear mines of water a more immediately interesting subject, to which Watt directed all his energies, with a success which astonished the world; the leading defect of Newcomen's engine, as improved by Smeaton, was the loss of heat arising from condensing the steam in the working cylinder. By careful experiments it was found that this loss amounted to about 32 per cent.; the steam being condensed in re-heating the cylinder each stroke, besides the loss of time in doing so. In this state Watt found the steam-engine, and by his vast improvements stamped his name upon it as if it had been his own original invention.

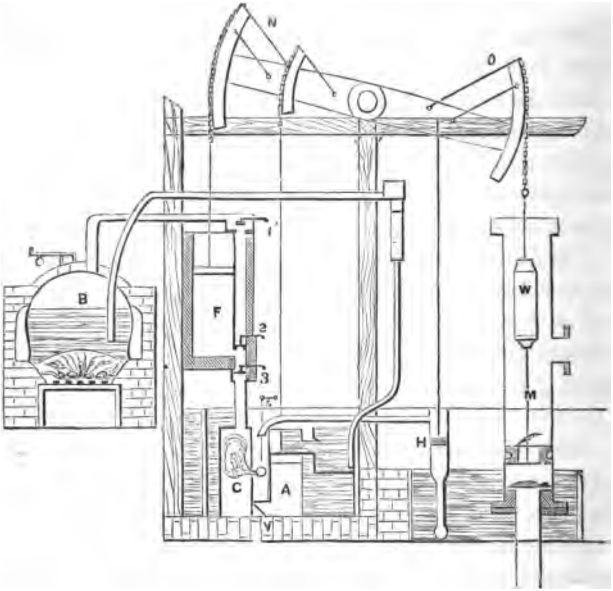


Fig. 35.—Watt, 1769.

On models of Papin's high-pressure and Newcomen's low-pressure engines he tried several experiments, which, from apprehension of danger from high-pressure steam, determined him in favour of low-pressure engines.

After several trials on condensing the steam in another vessel connected with the cylinder, in 1769 Watt patented the addition of a separate condenser, C, Fig. 35, to Newcomen's engine. The condensed steam, injected water and air were withdrawn from the condenser C, through a foot valve, by the air-pump A, to the hot well, from which a feed-pump supplied the boiler B. The pump H supplied the condensing water to the cistern, in which the air-pump and condenser are fixed. The conical steam-valve 1, the equilibrium passage-valve 2, the condenser passage-valve 3, and the injection-cock 4, were all opened and shut by suitable levers, worked by the air-pump rod. To maintain the temperature of the cylinder equal to that of the steam, Watt closed its top with a cover, having a central stuffing-box through which the piston-rod worked steam-tight. He also surrounded it with a "jacket" of wood or other non-conducting material, having steam between the jacket and cylinder. The air being thus excluded from the cylinder, the steam had to perform the duty done by the air in Newcomen's engine. The steam, therefore, entered by the top valve 1, to press down the piston and raise the water from the mine by the pump M, and to the boiler and injection-cistern by their pumps. The equilibrium passage-valve 2 was then opened, that the steam might pass to both sides of the piston, and the counterpoise weight W raise it and the air-cistern to the tops of their respective cylinders again. The equilibrium passage-valve 2 was then shut, and the steam-valve 1, condenser passage-valve 3, and injection-cock all opened, that the steam below the piston might pass to the condenser, and steam from the boiler to force down the piston again, as seen in the figure. The air-pump kept a vacuum in the condenser equal to about 12 lbs. pressure per square inch, which with rapid condensation and a hot cylinder saved the 32 per cent. lost by condensing in the cylinder, besides the gain in time—a very important step in advance of previous engines. Still this engine was only single-acting, that is giving out power during the downward, but none during the upward stroke of the piston.

Watt also proposed a rotatory engine, by having a piston working round a circular channel connected with the boiler and condenser, with valves, which were opened and shut by the steam and piston; but the valves were found to fail, and the piston to be injured in passing over the ports. Another plan was, by causing the steam to raise water through valves, as in Amonton's hot-air rotatory, but it was found to give out only a limited power. The double-acting cylinder was then invented, as supplying much of what was sought for by the rotatory class of engines.

Fig. 38.

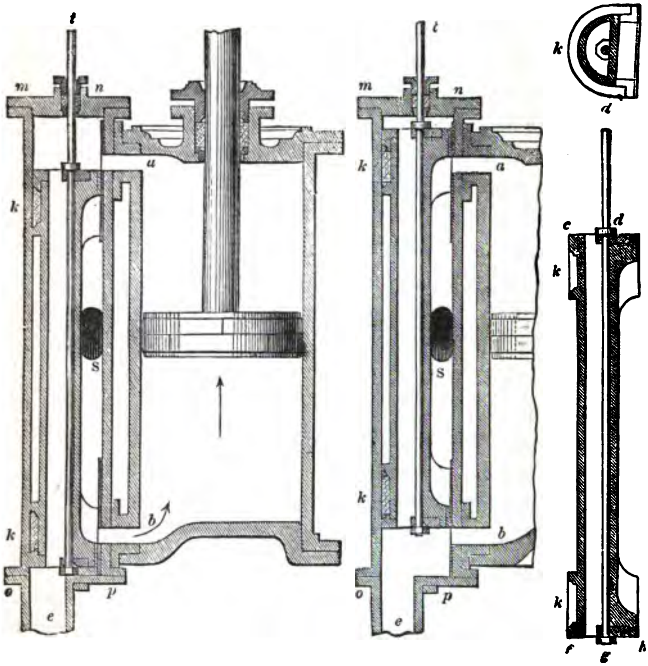


Fig. 36. Fig. 37. Fig. 39.

Watt's Double-acting Cylinders, 1782, and Murdock's Slide Valves, 1799.

By making the equilibrium-passage a steam-pipe or chest to admit steam alternately above and below the piston, with equal facility of escape to the condenser, in 1782 Watt made the steam both raise and force down the piston, thereby giving out power in both directions. This judicious improvement constitutes the double-acting engine. Fig. 36 is a sectional view of a double-acting cylinder, having the steam entering at S and passing by *b* below the piston, and the condenser passage *a e* open to the top of the piston.

In Fig. 37 the steam-passage is open by *a* to the upper side of the piston, and the condenser-passage by *b* from below the piston. The conical valves, as in Fig. 35, worked from the beam, opened and closed the steam-passages until Murdock, one of Watt's able assistants, introduced the eccentric motion and long D slide valve in 1799. Figs. 38 and 39 are sections of the long D slide valve.

The flat faces *h i* slide over the cylinder steam-passages *a b*, alternately opening them to the cylinder, and from the cylinder to the condenser. The convex stuffed faces *k k* press slightly against the steam-chest cover to keep the faces *h i* steam-tight over the passages or "ports" (as they are called) leading to the cylinder.

Whilst the single-acting force was downward, a chain conveniently connected the piston-rod to the beam, but as a flexible chain could not communicate upward motion, Watt tried a racked piston-rod worked by a toothed sector on the beam end. This proving noisy, and being easily deranged, in 1784 he patented the beautiful arrangement of levers, called the parallel motion, whereby to connect the vertical motion of the piston-rod to the circular motion of the end of the beam. By making A E and C D, Fig. 40, of equal lengths, but moving in opposite fixed centres, A C, the convexity of their equal curves would be opposite each other, when the centres A C were in the same plane.

On connecting them together by the link E D, its centre would move nearly in a right line. Another nearly vertical point is obtained by making B F equal to E D, and D F to B D. The centres of E D and B F would then move parallel to each other, but as B is a greater distance from the centre of motion, A, than E is, it would move through a greater height.

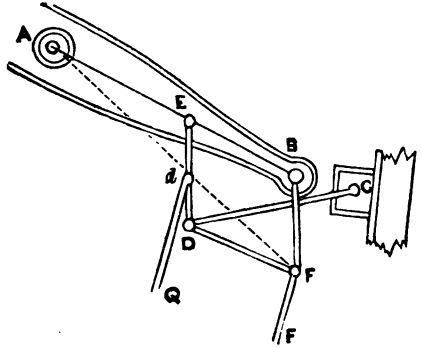


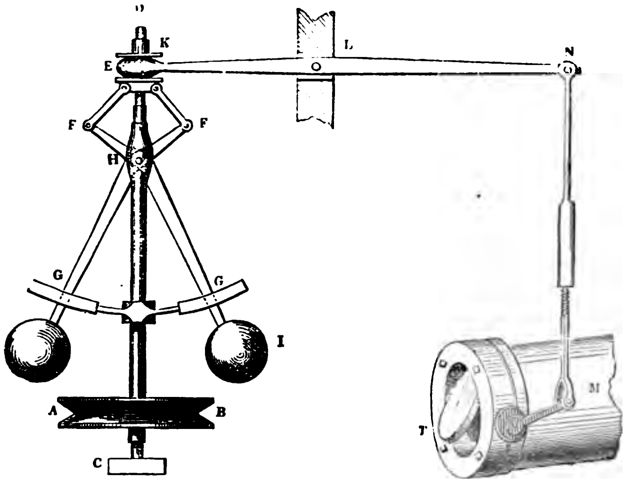
Fig. 40.—Watt's Parallel Motion.

In practice, the radius rod centre, C, is fixed near the line of the piston-rod, and the length of B F below the plane of A, that the links may be arranged to make F *d* the neutral points of the opposite curves.

The piston-rod is usually attached to the point F, and the air-pump rod to the point *d*, but the points may be varied according to the stroke required.

Parallel motions for beam engines, more geometrically accurate but also more complex than Watt's, have been proposed, and some of them tried, but failed to compete with it for simplicity and durability. To guard against irregular generation of steam affecting the motion of the engine, Watt introduced the throttle valve, worked by the governor previously employed in corn-mills to regulate the velocity of the stones.

In Fig. 41 the vertical shaft D is connected directly by the pulley A B to the fly-wheel shaft, that their velocities may be proportional to each other. The balls I I are jointed to D at H, and by the short levers F F to the sliding socket H. The lever E N moves on its centre L and connects the sliding socket H to the throttle valve T in the steam-pipe M. When the volocity of the engine increases, the balls recede from each other in the guides G G, as they accumulate centrifugal power, and draw down the socket H, which, by the lever E, partially closes the valve, as in the figure, and checks the flow of steam to the cylinder. When the velocity of the engine decreases the balls approach each other and raise K as they give out their acquired power, which opens the throttle valve for a free admission of steam to the cylinder.



Governor.

Throttle-valve.

Fig. 41.

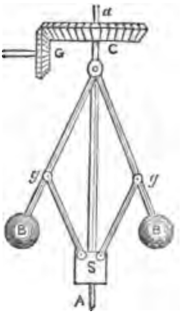


Fig. 42.—Governor.

Another form is by connecting the balls to the upper part of the vertical shaft, A *a*, Fig. 42, with the sliding socket, S, below. Single links, *g g*, then connect S with the balls, and bevel gear, C G, either at the top or below, connect the governor with the fly-wheel. The action of the governor is both delicate and good.

Combined with Fitzgerald's fly-wheel, these admirable inventions made the steam-engine so regular in its movements, that it became very desirable to apply it to give motion to machinery. Papin, Hulls, Wasbrough, Watt, and others, had all given more or less attention to convert its reciprocation into rotation, with no better result than the ratchet rotation, when James Pickard solved the problem in 1780 by applying the crank and connecting-rod to the steam-engine. He afterwards entered into partnership with Wasbrough, of Bristol, and several engines were erected under Pickard's patent.

Watt, however, complained that the crank was part of his design, unfairly obtained through one of his workmen, but rather than cause litigation, he invented and used the sun and planet rotatory motion during the existence of Pickard's patent, which rendered it of comparatively little value to the patentee, although a valuable arrangement.

The peculiar action of the sun and planet motion is deserving of notice. The sun-wheel A, Fig. 43, is fixed on the fly-wheel shaft, and the planet-wheel B is attached to the connecting-rod C leading to the beam. A separate link, D, connects the wheel A B of equal diameter and teeth together, that they may be in gear at all parts of their revolution. Planet-like, the wheel B revolves round the central wheel A, and as the centre of B's circuit is the periphery or circumference of A, the ratio of the diameters of their respective circles of revolution is as 2 to 1. Hence the sun-wheel revolves twice round its own axis whilst the planet-wheel revolves once round the sun-wheel.

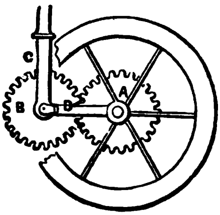


Fig. 43.
Sun and Planet Motion.

This is an advantage not possessed by the crank for working with a slow motion of the piston and light fly-wheel. The crank is, however, more simple and durable, which has led to its general adoption for converting reciprocating into rotatory motion.

After the first successful application of steam-engines to machinery, more graceful forms and superior finish were given to the various parts by Watt, until the steam-engine became a beautiful as well as a useful machine.

Little alteration either in the action or details of condensing beam-engines has taken place since Watt's time. It may, however, be remarked, that one of his best engines applied to Mr. Lacy's flour-mill, at Birmingham, was found to produce more coarse flour in grinding wheat than was done by water-power. This irregularity of motion was cleverly remedied by Mr. Buckle, one of Watt's pupils. To the fly-wheel shaft, A, Fig. 44, by means of the toothed wheels, B C, and lever D E, he connected an atmospheric cylinder F. The wheel B had twice the number of teeth in C, that their revolutions might be made in equal times. When the velocity of the engine tended to increase it, it had to raise the piston, P, against the air, but when the velocity tended to decrease, the pressing the air on P gave out power to B. This greatly improved the regular action of the engine, and secured the desired end of increasing the proportion of fine flour.

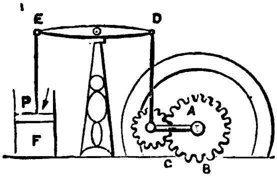


Fig. 44.—Buckle.

In small engines the beam is dispensed with, and fixed guides are used for the parallel motion. They are variously arranged according to taste or the duty required, but are all double-acting and alike as regards the action of the steam. Boilers have varied and still vary considerably. Newcomen and Smeaton employed a circular form with a convex top like a haycock, but Watt adopted a form resembling a covered waggon, from which it took its name. By improved flue, and other arrangements, the evaporation was increased to 8·6 lbs. of water by 1 lb. of coals, or 9·4 per cent. more than Smeaton's.*

Fig. 45 is a transverse and Fig. 46 a longitudinal section of a waggon boiler, with its modern self-acting feeding apparatus. One mode of feeding a high-pressure boiler without a pump has been explained by Fig. 28, and the plan of feeding a low-pressure boiler by its own action, without a pump, now claims our attention. The principle is by a column of water equal in weight to balance the pressure of the steam in the boiler. As has been shown, a column of water 34 ft. high has a pressure of 14¾ lbs. per square inch, which gives 2·3 ft. high for each 1 lb. of pressure in the boiler above the atmosphere, or 23 ft. for 10 lbs. pressure, besides the allowance necessary in practice. At the top of this columnal pipe *l*, and between it and the water cistern, a valve *k* is fitted, and kept in its seat by the weight *w*, whilst the other end of the lever *v* is connected to the stone float *m* in the boiler.

When the water falls low the float follows it and opens the valve *k* to admit water, but when the water raises the float the tension on *v* is relieved, and the valve *k* is closed by *w* to exclude the water. The water in the boiler is thus

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* It may be mentioned here that in 1782 Mr. Achard, and in 1790 M. Bettancourt, investigated the comparative properties of the vapours from water and from alcohol.

In 1790 M. Pronig wrote on the steam-engine, on the force of steam of different temperatures, and on combustion.

In 1793 Mr. Curr had an engine constructed on Savary's plan, which raised 120,000 lbs. of water one foot high by 1 lb. of coals, or about one-half of what Watt's engine did.

In 1795 Mr. Banks wrote on the useful effect of atmospheric engines, and in 1803 on the strength of the parts of engines.

In 1797 Mr. Curr gave the proportions of a 61-inch cylinder engine, capable of lifting 130,000 lbs. one foot high by 1 lb. of coals; and in 1801 Mr. Dalton published tables of the force of steam of different temperatures, which, with Mr. Southern's steam tables, have been superseded by those of M. Regnault, of France.

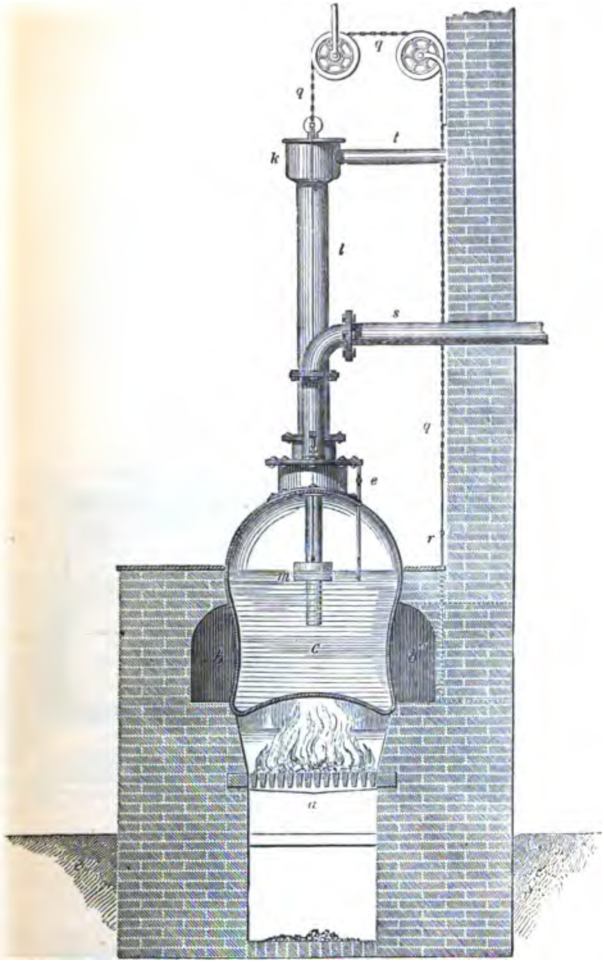

Fig. 45.—Waggon Boiler—Transverse Section.

made to regulate its own supply. The flue damper is also

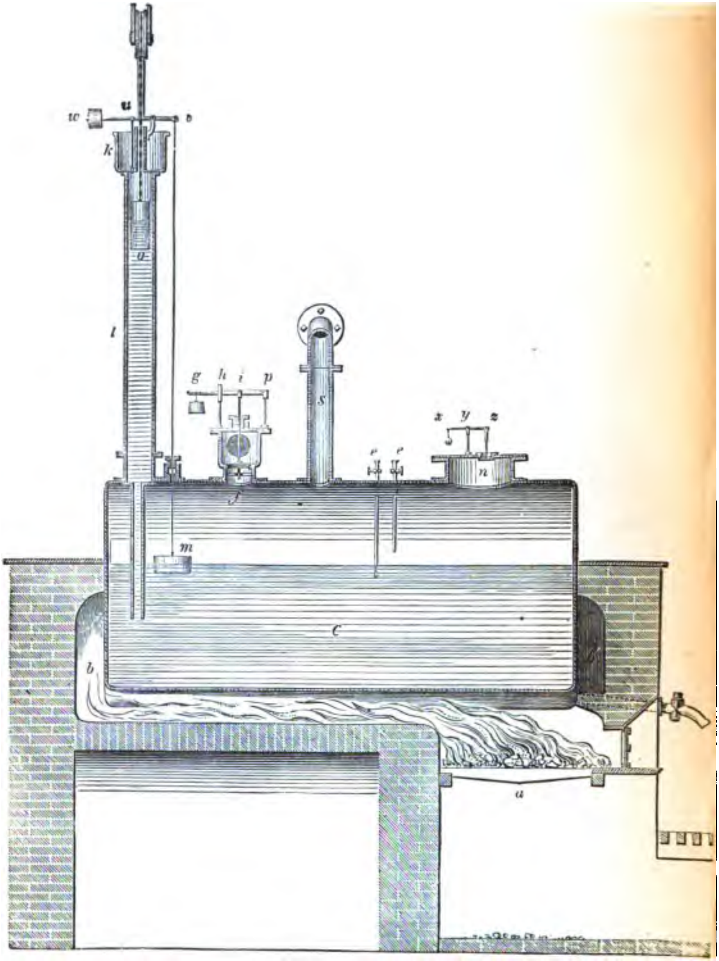

Fig. 16.—Waggon Boiler—Longitudinal Section.

ingeniously worked by the float *o*, in the column of water in *l*, passing by a line over the pulleys *q q* to the damper. The height of the water in *l* depending upon the pressure in the boiler, when that pressure increases and raises the water, the damper falls and partially shuts the flue to check the draught on the fire; but if the steam pressure decrease, the water falls, and the damper is raised to increase the draught and combustion. Two steelyard safety-valves, *g, h, i, p,* and *x, y, z,* regulate the pressure in the boiler. *e e,* the gauge-cocks; S, the steam-pipe leading to the engine.

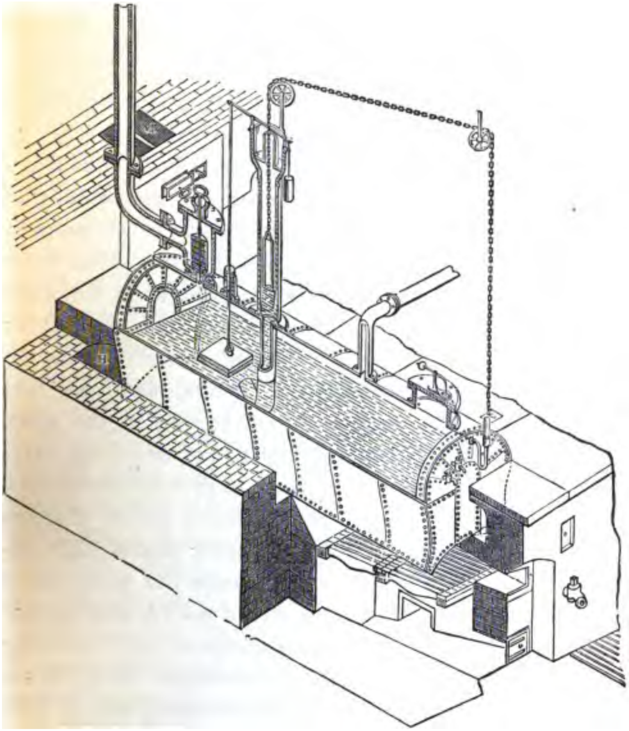

Fig. 47.—Waggon Boiler—Perspective View.

Fig. 47 is a perspective view of the complete self-acting waggon boiler, partly in section to show the water, fire-grate, and construction. To the left is shown a mercurial syphon gauge, and a glass gauge is also now usually placed in front to show by sight the height of the water in the boiler.

Fig. 48 is a glass gauge employed both on locomotive and stationary boilers, that the height of the water may be seen. *a a*, two stuffing-sockets, into which the glass tube is fitted steam-tight. It is connected to the front of the boiler by the cocks *r r*, and the cock *s* is for blowing through the tube or clearing it. The lower cock admits the water, and the upper one the steam, that their relative position may be the same in the tube as in the boiler. The water should always be some height in the glass tube, and at a recent fatal accident at Bristol the witnesses remarked that the boiler was out of gauge, signifying that the water could not be seen in the glass. This is a dangerous state, requiring careful but instant precaution to be taken to prevent an accident.

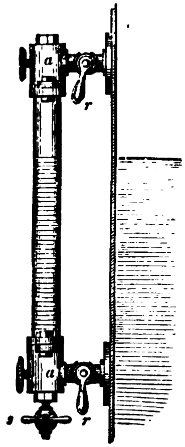

Fig. 48.

In 1776 Watt introduced the expansive action of steam cut off from the boiler, at Soho and other places. He calculated that when cut off at half-stroke the performance would be as 1·7, at one-quarter stroke as 2·4, and at one-seventh stroke as 3 in economy as compared with admitting steam during the whole length of the stroke. In 1778 one of them was erected at Shadwell Water-works, and in 1781 Hornblower patented the same principle, but expanded the steam in a second cylinder, which led Watt to patent his single-cylinder plan of expansion in 1782.

We have pointed out that the generation of steam and its economical employment were two distinct processes, each requiring to be duly attended to. This is very clearly shown in Watt's success, and also in the more recent corresponding success over Watt's engines. His first double-acting engine, erected at Albion Mills, London, realised a duty equal to raising 229,971 lbs. 1 ft. high, or rather more than double Smeaton's Long Benton engine. Yet there was barely 10 per cent. of this gained by Watt's boiler, leaving 90 per cent. due to the more economical application of the steam after it was generated.

With such able rivals as Smeaton, Hornblower, Trevithick, Bramah, Wasbrough, and others, often disputing the validity of his patents, or seeking to evade them, Watt's ultimate success has imperishably associated him with the steam-engine.

It should not, however, be forgotten, that but for the business habits and ample fortune of Boulton, his partner, Watt could not have maintained a struggle which involved an expenditure of about £78,000 to defend his patent rights and introduce his engines before any profit was realised. This enormous expenditure led to a renewal of his patents by the Privy Council.

1774—1800.—During the time that Watt was carrying out his steam-engine improvements other engineers were also engaged in the same field, both in France, in America, and in Great Britain, some of which will be noticed.

In 1774, Compte Auxeim and Perrier, of France, constructed and tried a paddle-wheel steamboat, but did not persevere with it. In 1776, Bushnell, of America, proposed a screw propeller for ships, which gave them a backward or forward motion, by reversing the revolution of the screw.

In 1776, Wasbrough, of Bristol, a rival of Watt, proposed to propel ships, raise water, or drive mills, by steam-engines with a ratchet-wheel rotation.

This enterprising engineer erected several of this class of high-pressure engines, and in 1781 was desired to fit one up at Deptford for the government, where soon after Watt appeared as a competitor, and Smeaton as a consulting engineer. On the ground that no reciprocating lever could produce "perfect circular" motion, Smeaton recommended that a water-wheel should drive the machinery, and a steam-engine raise the water to drive the wheel.

In 1781, a steamboat, 140 ft. long, was successfully worked on the Soane in France by the Marquis De Jeuffrey.

Hornblower, 1781.—The introduction of Watt's pumping engines into Cornwall, accompanied by Murdock, excited much local emulation to compete with or excel them, which has led to the great economy of modern Cornish engines. Amongst those local engineers, Hornblower, during Watt's patents, and Trevithick, principally after their expiration, most distinguished themselves,

In 1781, Hornblower patented a judicious arrangement of an additional cylinder, wherein to employ the expansive force of steam after it had done its duty in a smaller cylinder, on the plan of two cylinders, for the expansive action of steam.

For a section of the cylinders as improved by Woolfe, see Fig. 52, page 66.

The principle of expansion, the condenser, cylinder-passages, and details were all so similar to Watt's single-acting engine, that after a lawsuit he obtained payment for the use of his patents in Hornblower's engines, which were also only of the single-acting class.

The beam, mine-pump, counterpoise-weight, and chain connection, being similar to Watt's, need not be further described.

Besides Hornblower, various engineers attempted to construct efficient engines without infringing Watt's patents, but they nearly all failed to do so with low-pressure steam without a separate condenser.

Hornblower's rotatory engine had two movable pistons alternately moving round the steam cylinder, and acting as abutment valves to each other. A tappet valve in each piston was opened as it came in contact with the abutment one, which was then also set at liberty, and the other arrested by sliding levers behind it, and so on alternately.

Bramah, 1783—1797.—Bramah, another rival of Watt, proposed to propel ships either by paddle-wheels or by a screw, on the principle of the smoke-jack vanes. He also improved the construction of the two-way cock of Papin, by making it turn quite round, to equalise the wear.

His letter of 1797 to Sir J. Eyre, Chief Justice of the Common Pleas, strongly urging the demolition of Watt's patent, is one amongst many instances of one engineer seeking by casuistical pleading to injure another from interested motives.

Bramah's chief objections were, that Watt's engine was much more complete than the specification in detail, more particularly in, 1st, the cylinder top being closed; 2nd, ingenious piston and valve-rod stuffing-boxes in the covers; 3rd, gun-metal valves curiously worked; 4th, stoppage of the engine by any one defect; 5th, construction of stuffing-boxes; 6th, cylinder bottom closed, and steam acting above and below the piston; 7th, the "cuning" condenser, valves, and pumps. He concluded by declaring his inability to make an engine by the specification, and that the paten was thus invalid, but failed in the attempt to convince the Court.

Bramah also proposed three varieties of a rotatory engine, by a piston moving round a steam chamber divided into two parts, alternately opened to the boiler and to the condenser by slide valves working at right angles to the piston, and alternately pressed against it by an eccentric motion. He is, however, now chiefly remembered for his hydraulic press and his celebrated lock.

Fitch, 1783—1788.—In 1783, Fitch, an American, proposed a steamboat with six oar-propellers on each side, and so arranged that each opposite three should work simultaneously, and enter the water as the other six were leaving it. Motion was given to the oars by a steam-engine with twelve-inch horizontal cylinder and three-feet stroke, working a wheel 18 in. in diameter, suitably connected to the oars. In 1783, he moved a boat by paddles on the Delaware: and on trial at Philadelphia, in 1789, a speed of eight miles an hour was obtained; but Fitch's supporters having left him, he fell into poverty, and in despair drowned himself.

Rumsey, 1784—1793.—Rumsey's American steamboat was propelled either by poles in shallow water, or on Hull's plan, or by pumping water in and out of a pipe along the bottom of the vessel. The pump was 2 ft. in diameter; and during the upward stroke the water entered by a valve, which was shut by the returning stroke, and the water expelled at an orifice about six inches square in the stern of the vessel. In 1793, a speed of four miles an hour was realised on the Thames, against the wind and tide, by one of Rumsey's boats.

Oliver Evans, 1784—1804.—While Watt was devoting his talents to the steam-engine in Great Britain, a kindred spirit in America, Oliver Evans, was devoting all his energies also to extend its usefulness in the New World. Watt preferred low-pressure steam; Evans, high-pressure steam.

Strongly impressed with the locomotive capabilities of high-pressure steam-engines to move ships or waggons, in vain Evans sought to obtain pecuniary means to test his ideas. His locomotive opinions were derided as emanating from insanity, and he found no Boulton to aid genius struggling against poverty and prejudice. He introduced the cylindrical boiler with an internal flue, and leading back below the boiler to the chimney. To further economize fuel, the exhaust steam was made to pass spirally through a pipe in a cistern of water to heat it for the boiler, as also done by Trevithick afterwards.

In 1804 he showed the capability of his engines for both land and river locomotion, by temporarily fitting one of them on a rough waggon, and afterwards in a boat.

Murdock, 1784—1789.—This able assistant of Watt survived him about twenty years, leaving a name intimately associated with Watt's steam-engine in Cornwall, where he was much respected. The eccentric motion and long D slide-valve were his invention, and as a modification of this plan is employed in locomotives, its action will be explained. The hole A in the circular sheave B C D is at some distance from its centre E, which gives it an eccentric motion round the crank shaft A, on which it is fixed. Since A is the centre of motion and E the centre of the sheave, the distance between them is equal in effect to a crank. If that distance is two and a half inches on each side of A during each revolution, the point F of the eccentric strap and rod, B C, D F (fitted so as to move easily round the sheave E), would move 5 inches, thus converting rotatory into rectilinear motion.

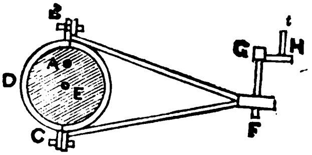

Fig. 49.—Murdock's Valve-gear.

For vertical cylinders the levers F G H, fixed on the centre G, connect the eccentric rod with the slide-valve rod *t*, Fig. 49. For horizontal cylinders, the connection may be direct, or by intermediate mechanism, as will be shown.

Murdock's rotatory engine consisted of two toothed wheels working in a steam-tight casing, and gearing into each other. The steam enters directly against the teeth then in gear, and, forcing them round, passes out at the other side to a condenser.

The cylindrical slide-valve, the cylinder boring-bar, and iron cement for steam-pipe joints, were a few of his contributions to the steam-engine.

He also introduced gas, and the brilliant gas illumination of the Soho works at the peace of Amiens attracted universal attention. A model of an oscillating engine, and also a model of a locomotive engine, both made by Murdock in 1785, were exhibited in the Industrial Palace as the earliest working models of these engines in this country. The locomotive model will be described in the next chapter. The object of the oscillating cyclinder C, Fig. 50, is to keep the piston-rod in a line with the crank-pin, without a parallel motion or separate connecting-rod. For this purpose the

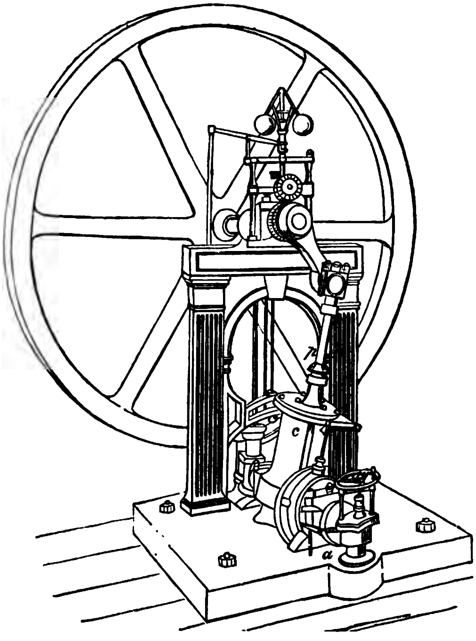

Fig. 50.—Penn's Oscillating Engine.

cylinder is suspended on two hollow centres, which serve as steam-passages. When the crank is at its greatest angle the cylinder takes the same angle, and in like manner at the opposite extreme, or any other part of the revolution. The oscillating engine early constructed by Messrs. Penn, of Greenwich, is shown in Fig. 50.

Messrs. Joyce, of Greenwich, constructed a double-cylinder pendulous oscillating engine of 40 horse power. The pendulous engine is so called from its cylinder being suspended from its top end on centres like a pendulum, with the piston-rod working out below.

Fig. 51 is a front view of one of Joyce's single-cylinder pendulous engines, showing its arrangement and mode of action.

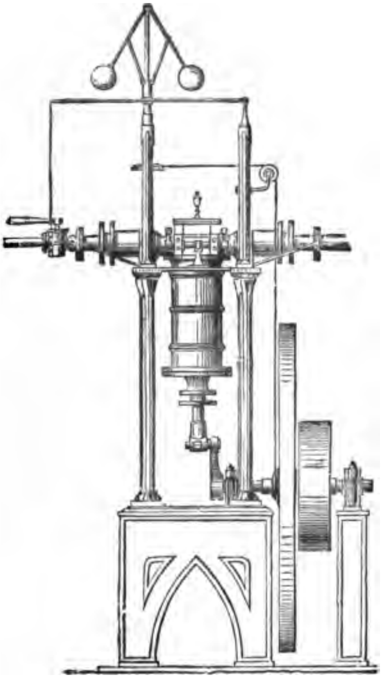

Fig. 51.—Joyce's Pendulous Engine.

Patrick Miller, 1787—1796.—This enterprising Scottish gentleman spent about £30,000 in seeking to improve the naval and artillery defences of the nation, yet, like many poor inventors, he was neglected. The carronade was Mr. Miller's invention; and in naval efforts he constructed some twin and treble keeled paddle-boats. With two keels, the paddle-wheel worked between the keels; and with three keels, one paddle-wheel on each side of the central keel. The keels were made to work simultaneously by one steersman. With a double-keeled boat a speed of four miles an hour was obtained in the Frith of Forth, by five men working the paddles by a capstan. The boat was 60 ft. long and 15 ft. wide.

In these experiments he was actively seconded by his children's tutor, Mr. Taylor, who successfully urged him to employ a steam-engine to turn the paddle-wheels. In 1788 the first trial was made on Dalswinton Lake, in a double pleasure-boat, worked by one of Symington's ratchet-motion engines with a four-inch cylinder. With this very small engine a speed of five miles an hour was obtained, which led to a double engine of the same class, with eighteen-inch cylinders, being applied to a boat on the Forth and Clyde Canal in 1789-90, and a speed of seven miles an hour realised. Whether the cost of these trials had exhausted Mr. Miller's resources, and a gentlemanly delicacy prevented his soliciting aid, or other causes operated to induce him to give up his steamboat experiments when they had thus proved successful, is not known; but from this time he turned his attention principally to agricultural affairs. Mr. Taylor received a pension of £50 per annum from Lord Liverpool; and in 1837 each of his four daughters received £50 as a gift from Lord Melbourne's government, for his aid in introducing steamboats.

Earl Stanhope, 1790.—As a practitioner in science and art this nobleman holds a high position, regarding it as more honourable to gain an independence as a mechanic than live upon the bounty of friends or on the public purse.

In 1795 he tried a steamboat moved by paddles, which opened to act against the water, but closed to be drawn through it, like a duck's foot, and with a flat-bottomed boat attained a speed of three miles an hour. R. Fulton, the

American steamboat engineer, showed his lordship drawings of a steamboat in 1793-4, and it is said urged the advantage of paddle-wheels over the duck-foot oars, but without effect.

Sadler, 1792.—Sadler proposed rotation by steam issuing from arms, at great velocity within a case, and renewing the motion by condensing the steam internally, so that the air became the motive power. His reciprocating engine had no beam or parallel motion, but had vertical guides for the piston and air-pump rods to work on by small wheels. The air-pump rod was extended to give motion to a lever pressing the valves and cocks. Although inferior to Watt's, yet, in a competition, the naval authorities preferred Sadler's engine to that of Watt at that time.

Nuncarrow proposed an ingenious plan of applying a condenser to Savary's engine, for raising water to turn a wheel and drive machinery from this water-wheel.

Fenton Murray and Wood, of Leeds, improved the details of the valves, air-pumps, and boilers, along with horizontal cylinders, where most convenient. They also fitted a throttle-valve in the chimney, worked by a small cylinder fitted on the boiler, which partially closed the chimney when the steam was high, but left it open when steam was low in the boiler.

J. Robertson, of Glasgow, proposed a long cylinder with two pistons, that the steam, which usually escaped past the upper piston, might act on the second one, and erected some engines on this plan, which worked satisfactorily, until a better class of pistons and cylinders rendered such a plan unnecessary.

At the expiry of Watt's patent, there were only about 1,400 horse-power of his engines at work in London, Manchester, and Leeds, so much had prejudice and interest done in retarding the general introduction of this valuable machine.

Woolfe, 1796—1804.—By making Hornblower's engine double-acting, like Watt's, and using higher pressed steam generated in an improved tubular boiler, Woolfe produced a very efficient class of engines. The boiler A. B, Fig. 52, consisted of six, eight, or more metallic tubes, placed transversely across the fireplace and flues, and connected to a main steam receiving-pipe A, under which a partition wall divided the flue into two. The fire acted directly on the three first tubes, and the products of combustion passed alternately over one tube and below the next until they reached the back of the boiler, when they passed round the end of the partition, and continued their course alternately over and under the tubes until they reached the chimney at the fire end of the boiler. Two half-length steam receiving-pipes were over this part of the transverse pipes, and also connected with the main steam-chamber A, from whence the steam passed by the pipe S to the the cylinder steam-chest C, from which the valve V admits it alternately above and below the piston in D, and also alternately from the top of D to the bottom of E, or from the bottom of D to the top of E, by the double connecting passages 1, 3. The con-

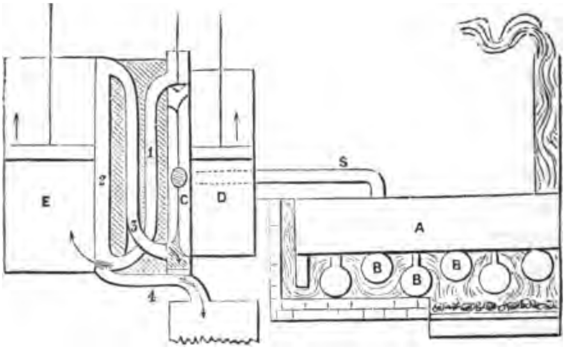

Fig. 52.—Woolfe.

denser passage 2 4 communicates with both sides of the piston in E, that it may work in a vacuum. Both the pistons are thus simultaneously moved upwards or downwards at the same time. Sim's engine of this class has the two cylinders on the top of each other, like Cartwright's cylinder and air-pump; but M'Naught places the small cylinder at one end of the beam, and the larger one near the other end, that they may work at right angles to each other, like two separate engines. Both classes are favourable for efficacy and economy. In these varieties of Hornblower's engine there is the uniform force of the small piston combined with the decreasing force of the large piston, which gives a more equal mean than is obtained from an equal expansion in one cylinder, although, as has been shown, the total force evolved is greatest for one cylinder.

Trevithick, 1790—1816.—From 1790 to 1800 this able engineer, in connection with Bull, one of Watt's former workmen, erected several engines with double-acting cylinders on Watt's plan; but, to evade his patent, Bull worked the piston-rod through the bottom instead of the top, which, on a trial, the judges held to be legal.

Trevithick's acquaintance with Murdock and his models at Redruth led to his celebrated locomotive of 1803, combining the principal features of both models in one engine. Like Evans, Trevithick preferred high-pressure steam, and his first patent engine had a spherical boiler set in a fire-brick case, with a heating flue all round. The cylinder was fitted into the boiler to maintain its temperature, and a two-way cock, worked by a double-eccentric cam on the fly-wheel axle, admitted steam to and from the cylinder. Another plan was to suspend the case, boiler, and cylinder on centres, that the piston might adapt itself to the angularity of the crank; or to suspend the cylinder only, like Murdock's. He afterwards adopted a cast-iron boiler, nearly similar in form to Evans's, as in Fig. 53, where the fire is placed in one end of the central flue, whilst the other end terminates in the chimney. The cylinder is fitted into the boiler, and the fixed guides 1, 2 keep the piston-rod in a line with the cylinder. A connecting-rod down each side communicates the piston-motion to the cranks and fly-wheel. The exhaust-pipe passed through the cistern W to heat the water for the boiler, also similar to Evans's plan; but Trevithick's terminated in the chimney, which ultimately led to that important part of a locomotive, the blast-pipe. P the cold-water pump, M the syphon mercurial gauge, S the steel-yard safety-valve. The boiler-pump was on the opposite side.

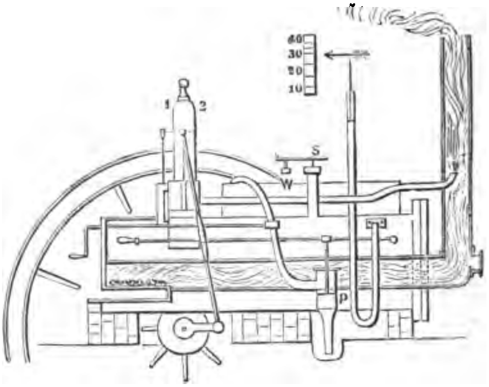

Fig. 53.—Trevithick.

In 1802, Trevithick patented a common-road locomotive engine, which was successfully tried near London, and on a mineral railway in 1805; but, having run off the road, it lay in the ditch as if a worthless combination of mechanism. Like Evans's, Trevithick's success was greatest with fixed engines, and, after the expiry of Watt's patents in 1800, he introduced high-pressed steam, expanding to a low pressure, with so marked economy, that the Court of Spain sent him out, with regal honours, to drain the silver mines of Peru. The locomotive, neglected by the public, was necessarily neglected by the inventor for the more inviting Spanish commission, which, however, also ended badly; and Trevithick returned unrewarded to England, and continued to devote his talents to improve the steam-engine.

Symington, 1786—1804.—In 1786 Symington exhibited a model of a locomotive at Edinburgh. He also tried to combine Newcomen's atmospheric plan with Watt's separate condenser, and yet to evade the patent, but failed to do so.

Symington's experience in Scotland with Messrs. Miller and Taylor resulted in his constructing the first paddle-wheel steamboat of the modern class. Supported at the time by Lord Dundas, it was called *Charlotte Dundas*, after his lordship's daughter. Fig. 54 is a diagram of its machinery. The boiler B supplied steam to the horizontal double-acting cylinder C, whose piston-rod is kept parallel by the motion M, and connected by a rod and an outside crank to the paddle-wheel W, to produce rotation in the usual manner. The condenser D and the air-pump A are worked by the cranked lever E, connected to the piston-rod motion. This is a simple and effective plan, which, excepting the condensing apparatus, has been adopted in modern

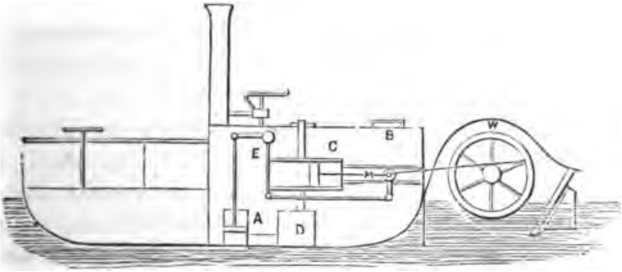

Fig. 54.—Symington, 1802.

locomotive engines. In 1802 this boat, with a twenty-two-inch cylinder and four-feet stroke, drew two loaded seventy-ton boats, against a strong breeze, at the rate of three and a half miles per hour; but the canal proprietors objected to its use, for fear of the waves injuring the banks. Symington's means were gone, and this efficient steamboat was laid up in Scotland, near Brainsford, for years exposed to public view, a valuable combination, yet unable to find public support.

When reduced to poverty, and his friends appealed to the government on his behalf, Symington was presented with £100 from the Privy Purse in 1825, and afterwards with £50!

Cartwright, 1797.—This reverend and talented gentleman patented an ingenious parallel motion, metallic piston, an air-pump, and external condenser. He also proposed a rotatory engine with three pistons and double admission and exit passages for the steam. Power looms, and carriages without horses, were also amongst his plans.

In his reciprocating engine he proposed to use alcoholic vapour, which external condensation did not affect, so that it could be used again and again. His parallel motion was by having two wheels of equal diameter connected to a cross head on the piston-rod, and as the cranks were always opposite to each other, their obliquity was balanced to work the piston-rod vertically. The air-pump was immediately below the cylinder, and worked by one rod for both pistons.

Hall's patent tubular condenser, as applied to the *British Queen* and other steamers, is an improved form of Cartwright's plan of condensing by external cold. The metallic packing of modern pistons are modifications of Cartwright's piston. In this way the ideas of one inventor are adopted by others in new combinations of greater efficiency.

Fulton, 1793—1807.—This able and persevering man had long been engaged in promoting various plans of steam navigation, and other projects, before he saw the forsaken steamboat on the Clyde Canal. Having visited Scotland, and made himself acquainted with the construction and performances of Symington's neglected steamboat, Fulton returned to America, and successfully introduced steamboats on the Hudson, between New York and Albany. To Fulton is due the credit of coming to this country and carrying into practice, with the most beneficial results to mankind, a British combination neglected by the British nation. It is a singular yet melancholy fact, that at the same time the two most remarkable inventions of any age, practical steamboats and practical locomotive engines, were both lying for years as a "reproach" and a "by-word" on the highways of Great Britain—Symington's steamboat on the Forth and Clyde Canal, Trevithick's locomotive engine in a ditch by the roadside! Both the inventors died poor, neglected men. America had also her neglected Evans, and France her Cugnot. May we not, therefore, the more appreciate such men as Boulton, who rescued Watt from world-wide difficulties?

Fulton's first steamboat, the "Clermont," built in 1807, was 130 ft. long, 16½ ft. wide, 7 ft. deep, and 160 tons burden, worked by one of Watt's double-acting engines, with a vertical cylinder, two feet in diameter and four feet stroke, connected to the paddle-wheels, W W, Fig. 55, fifteen feet diameter and four feet broad, by the side levers and outside connecting-rods 1, 2, and gearing S *b*. Each paddle-wheel was on a separate axle B, C, having on its inside end a crank 3, 4, for the connecting-rod, and a toothed wheel, *a b*, to gear

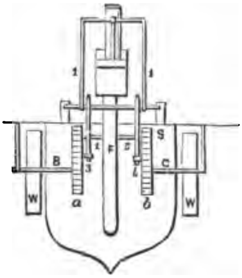

Fig. 55.
Fulton's Steam-Boat, 1807.

into another on the fly-wheel shaft, S. As there was only one engine, a large fly-wheel, F, worked in the centre of the boat between the ends of the paddle-shafts, to continue the rotation past the dead points of the crank, as shown in Fig. 55.

American river steamboats are now celebrated for their size, superior accommodation, number, low fares, and speed, over those of any other nation. On the Hudson, for instance, where steam navigation for hire was first introduced, besides many smaller vessels averaging 200 feet in length, there are upwards of ten floating steam-palaces averaging 310 feet in length. Two of them are above 1,000 tons burden, and many of them travel twenty miles an hour with safety, for explosions are all but unknown on this river. From New York to Albany, about 150 miles, the fare is only 2*s.* 2*d.* in these floating palaces. This is a higher velocity than that of our parliamentary trains, and at one-fifth the cost to travellers.

Bell, 1800—1812.—In 1800 Mr. Bell fitted a four-horse steam-engine in a small vessel, and sailed from the Clyde to the Thames at the rate, as stated, of seven miles per hour. The extraordinary appearance, it is said, led a sloop of war to give chase in the Bristol Channel; and on an Admiralty inspection in the Thames, considering the invention of no value, Nelson remarked, "Gentlemen, if you do not take advantage of this invention, you may rely on it other nations will." Even this mediation of England's great naval captain failed to secure Bell any better treatment than had been meted out to Savary.

The machinery was taken out, and the boat sold. Another application in 1803 shared no better fate, and in 1812 Mr. Bell constructed the *Comet* steamboat of 25 tons, worked by an engine of about three horse-power, which realised about five miles per hour on the Clyde. As soon as Mr. Bell had overcome popular prejudice and obtained passengers, powerful companies started into existence, which deprived him of any reward for his meritorious exertion and heavy pecuniary sacrifices.

Stevens, 1804.—With a Watt's engine of only four and a half inch cylinder and nine inches stroke, supplied with steam from a boiler consisting of eighty-one horizontal copper tubes, one inch diameter and two feet long, Stevens, of Hoboken, in America, propelled a steamboat four miles an hour by a screw, on the principle of the smoke-jack vanes. The tubular boiler deserves notice from the number and position of the tubes, being similar to the modern locomotive boiler, excepting that the latter makes the tubes flues, whilst Stevens made them boilers, as was generally done by all common-road steam-engines, with steam from 200 lbs. to 300 lbs. pressure per square inch.

Stevens also constructed one of his boilers six feet long, four feet wide, and two feet deep, with one-inch tubes, to give a heating surface of 400 square feet.

In 1815 Ralph Dodd had a fourteen-horse engine fitted into a seventy-five ton boat, and during a stormy voyage from the Clyde by Loch Ryan, Dublin, Milford, to London, of about 758 nautical miles, run in 122 hours, he clearly showed the power of steam to contend against dangers which would have destroyed sailing vessels.

In 1818 Mr. David Napier successfully prosecuted ocean steam navigation, and in 1822 the *James Watt*, of 100 horse-power and 440 tons burden, ran from Leith to London, realising a speed of ten miles an hour

Since that time steam navigation has steadily progressed, and engines with their pistons connected directly to the crank, without any side levers or beams, are now preferred.

Steam has not attained its eminence without competition;

for, besides hot air, gunpowder, gun-cotton, ether, turpentine, alcohol, and explosive gases have all been tried as sources of motive power, and they still occasionally attract notice.

In 1791 R. Street dropped turpentine on hot iron, and exploded the vapour formed below a piston to produce motion.

In 1807 M. de Revaz moved a locomotive carriage by exploding a mixture of hydrogen and air in a cylinder by electricity.

In 1820 the Rev. M. Cecil discussed the comparative merits of steam and an explosive mixture of air and hydrogen, and proposed an engine to be worked by the explosion of air and hydrogen.

In 1823-24 Mr. S. Brown constructed a similar but greatly improved explosive gas-engine. Mr. Brunel tried a carbonic acid gas engine; and, modified, these plans have been revived, in America, with alcoholic gas engines.

Electricity has also been tried somewhat extensively, and both in Great Britain and in America electro-locomotives have realised from six to ten miles per hour with a limited load.

Several models of engines, driven by electricity, were exhibited in 1853. Amongst the latter was one by James Squires, driving a sectional model of one of the large broad-gauge engines, and another, producing rapid motion, by William Bickle. The latter had two electro-magnetic coils on each side of the centre of two levers, having broad parts immediately over these coils for attraction and repulsion alternately, and their other longer ends were connected to the fly-wheel axis, as in the steam-engine. By a self-acting cut-off valve, for the electric current at opposite angles at the same moment, a double-cylinder action is obtained, which in the small model spun round the fly-wheel with great rapidity.

Squires's plan was by placing the poles of a horse-shoe electro-magnet within the attractive distance of the arms of a fly-wheel, and by a self-acting cut-off produced rotation with considerable power.

Ericsson, 1829—1853.—In England, Ericsson designed the *Novelty* locomotive tried at Rainhill, in 1829; the rotatory-engine steamboat, tried at Liverpool in 1832-33, with great velocity in the water, but excessive consumption of steam; the hot-air engine, tried in 1834 at Braithwaite and Co.'s, London, with success as a motive power, but failure from friction in the hot cylinder; and his screw-propeller steamboat of 1837, tried by the Admiralty on the Thames, with much success.

The American Captain Stockton had a larger vessel built with Ericsson's propeller at Liverpool in 1838, and sent to America in 1839, where, as the *New Jersey*, it plied on the Delaware with success. Screw-propellers are now generally preferred.

Since that time Captain Ericsson has found B. Kitching, Esq., of New York, to aid him in testing hot-air power on a truly magnificent scale of operations.

The principle of caloric or hot-air power is heat, the same as in steam or hot water. In the former air is expanded, and in the latter water is expanded to give out elastic power.

As we have before shown, air is estimated to expand $\frac{1}{480}$th of its bulk for each Fahrenheit's degree of heat added to it; and as its pressure is nearly in the ratio of its volume and space, it follows that by adding 480° of heat to the ordinary air, it would double its volume, or, if confined, double its pressure. This would give a total pressure of two atmospheres, and, independent of a vacuum, leave one atmosphere 14·7 lbs. per square inch of available power, which inventors seek to apply as a motive power instead of steam.

The difficulties hitherto defeating the success of hot-air power are, the high temperature of about 570° required in the working cylinder, volatilizing or carbonizing any known lubricant, and the excessive friction thereby occasioned.

Perkins experienced the same difficulty with his high-pressure steam, but then he would have at least 33 times the power of air of equal temperature, or upwards of 1,000 lbs. per square inch.

The preceding pages have shown that hot-air engines are as old as steam-engines, and that in design they were not surpassed before Newcomen's time, nor yet supassed by caloric engines as regards heating the air in a separate vessel from the working cylinder. In engines, both rotatory and reciprocatory, Cardan, Branca, Amonton, Leupold, Hautefeuille, and others have sought to produce an effective hot-air power, or, as in Wilkinson's and Houston's recent patents, by air and steam combined in the same boiler or cylinder.

The obvious safety from explosion, and the lightness of the whole engine, led Sir G. Cayley, in 1804, to propose a hot-air locomotive, which was tried in London in 1807. About 1819-20, Mr. Greenwood had a hot-air engine made and tried at Manchester, with one forcing-in air-pump and another exhausting air-pump, but the friction led to its disuse.

In 1834 Mr. Stirling had a reciprocatory hot-air engine made by his brother at Dundee, where it worked for several years with much economy of fuel, but, as in others, the friction was a serious drawback to its real utility.

This engine had a wire-gauze absorber of escaping heat, which it restored to the cold air entering through its meshes to the cylinder, and a similar gauze-chamber is an important chamber in Ericsson's caloric engine. This gauze-reservoir Mr. Stirling called a refrigerator, from its cooling the escaping air; but Captain Ericcson calls it a regenerator, from its heating the entering air.

So far as we can learn, Ericsson's engine is a modification of Sir G. Cayley's and Mr. Stirling's, with his own compact arrangement of the mechanism. We now describe it, to the best of our judgment, as follows :—

The hot-air cylinder, about fourteen feet diameter, has placed at some distance above it the air-supply cylinder, about eleven and a quarter feet diameter, and the open ends of both cylinders facing each other. In the top of the supply cylinder there are two valves, of which one part opens inwards, to admit air, and another part opens outwards, by which to force the air out by the pipe into the airometer. In the bottom is placed a number of thicknesses of wire gauze, having a surface of many square feet, through which the air passes both to and from the working cylinder. The slide-valve alternately opens the ports, to admit air to the cylinder, and from it to the atmosphere. The lower part of the working piston is extended downwards, but not fitting the cylinder, that its expansion may not injuriously affect it, whilst it guards the air-tight part of the piston from the direct action of the hot air. The pistons are connected together, which preserves their parallelism, and a bell-crank lever, connected by a link or slot to the main piston-rod, gives motion to the machinery. As the cylinders are only single-acting, it requires four cylinders to give the rotatory power of two double-acting steam cylinders, and they are placed two and two on each side of the paddle-shaft, in lines parallel with the line of the vessel. The connection with the crank-shaft is so arranged, that each pair of acting cylinders work at right angles to each other, as in the double-crank engines.

The action is regulated by the slide-valve, admitting air to the cylinder where it is exposed to the fire; and as it expands by the heat, both pistons are raised simultaneously about six feet high. The large piston gives motion to the machinery, and the small one forces the air to replace that withdrawn from below, and thus balance the supply and demand of air. As the pistons are in an equilibrium of atmospheric pressure on both sides during the downward stroke, their own gravity, aided by the full-power action of the other cylinder, carries them to the bottom ready for another upward stroke again.

At this point the wire-gauze recipient or heat-ometer comes into action, by absorbing heat from the escaping hot air, which is again re-absorbed from the wire gauze by the cold air passing through it to the cylinder. Its action is precisely similar to that of the respirator worn by invalids or others in cold weather; for, in both the human and mechanical arrangement, heat is absorbed by the wire gauze from the expelled air, and returned to the air which enters through it to the lungs or to the cylinder.

In Ericsson's engine it is stated, that the heat so "caught" in escaping and returned to the cylinder is about 460° out of 510° of added heat to that in ordinary air, and requiring from the fire only about from 50° to 70° to replace that lost by radiation or other causes; and the generation and consumption of caloric or heat is thus adjusted.

In this way the actual consumption of heat is economized to about 25 per cent. of that required for steam; but the amount of friction in passing through the gauze is not as yet publicly known in England, and is highly estimated.

The name of regenerator has been objected to, as implying a creator of power, whilst it is only a recipient of heat which would otherwise be lost, and perhaps heat-ometer would convey a clearer idea of this important "picker-up" of $\frac{14}{18}$ths of the escaping heat for further duty. If a similar proportion of the 1,180° of heat in 30 lbs. of steam could be returned to the boiler, the economy of fuel would be very decided, since at most only about $\frac{1}{8}$th of it can be so retained in water heated, by waste or exhausted steam, to the boiling point.

With a practical solution in progress, so much more satisfactory than any theoretical one, it will be unnecessary to discuss the relative expansion of steam or flame and air by heat, since the power of the latter, if safer, is much more confined than that of the former.

The pressure on the supply piston acts against the working piston, at a mean force from zero up to full pressure, about half stroke. In the recent trials a working pressure of 12 lbs. was said to be realised, and, taking 10 lbs. as the full mean pressure on the supply piston, an estimate of the power may be thus arrived at:

	sq. in.		lbs.		lbs.
Area of working cylinder . .	22,167	×	12	=	266,004
Area of supply cylinder . .	14,426	×	10	=	144,260
Which leaves an available power . . .				=	121,744

to move machinery and overcome the friction of the engine, or about equal to 24 lbs. effective steam on an 80-inch piston. The power, therefore, of Ericsson's two pairs of cylinders, with 6 feet stroke, would be about the same as two 80-inch double-acting cylinders with a similar stroke, and 24 lbs. high-pressure steam, or 12 lbs. steam in a condensing engine, whose vacuum supplies the other 12 lbs. Double-acting cylinders would however be as valuable to caloric as to steam-engines, which were also single-acting till Watt's time.

The power given out by hot air is, however, variously regarded by the most experienced engineers, who doubt its success, which time will soon solve; but that power is obtained from hot air is quite evident from the example given, less the additional friction of four pistons instead of two in the steam-engine, leaving the air-pumps as equivalent to water-pumps and parallel motion.

From working models of other hot-air engines there appears to be no difficulty in making any number of strokes per minute up to at least 150 or more, but past experience points to friction as the chief obstacle to hot-air engines. Against the disadvantages of friction, unequal expansion of the cylinder, oxidation, or leakage, to be overcome by skill and ingenuity, are to be placed the advantages of safety from explosions, economy of fuel and of space,—all considerations of importance in navigation,—and other mechanical operations.

The practical results, therefore, of Ericsson's experiments will be deeply interesting in any point of view; but it will be most satisfactory to learn that he triumphs over those mechanical difficulties which have hitherto retarded the progress of hot-air engines.

Portable Farm-engines.—In the mine, in the factory, on the ocean, and on the rail, steam had produced results of vast importance before its aid was valued by agriculturalists. Indeed, its first essay to do the work of horses was resolutely opposed as injurious to their interests; but other opinions now prevail, and steam assists the producers of the staples of food and clothing, as it has long done the manufacturers of metallic, textile, or other products of science and art.

Under the auspices of the Royal Agricultural Society, the farm-engine has been brought to rival in economy the factory-engine.

Fig. 56 is a fire-box end view, and Fig. 57 a smoke-box end view, of an engine constructed and exhibited in 1851. To the fire-box B is fitted the exposed cylinder C, and the parallel motion D is fitted to the boiler A. The fly-wheel H drives the farm machinery, and is connected to the piston by the rod F, whilst the eccentric rod E works the slide-valve. I the water-tank, G the governor, A the fire-

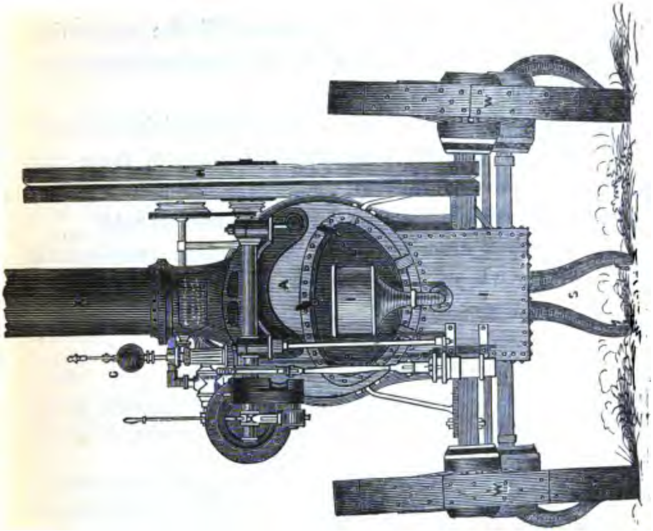

Fig. 57.—Smoke-box End.

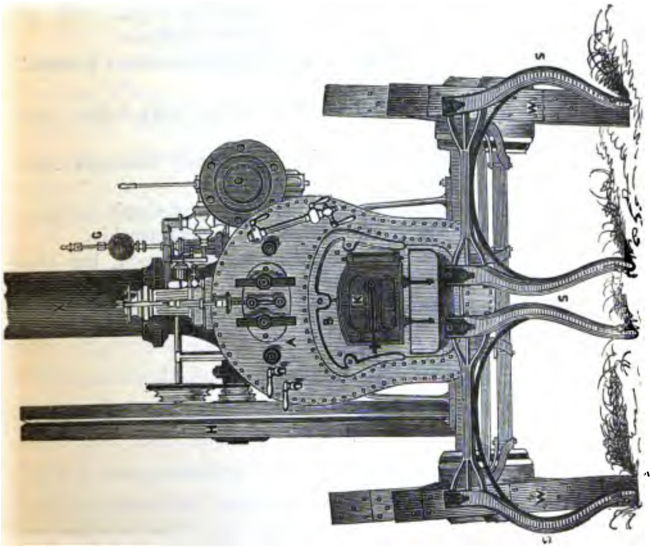

Fig. 56.—Fire-box End.

door, S the shafts, V the safety-valve, W the supporting wheels. The gauges, steam-pipe, and regulator handle are seen on the end views.

Amongst the farm engines in the Crystal Palace of 1851 were several of good workmanship, but many of them had exposed cylinders, as if Watt and others had never gained largely by protecting the cylinders from external cold.

The following description of the engines exhibited in 1851, and the results of the trials, are condensed from the Jury Report of the Exhibition :—

General Description of the Engines tried.

Hornsby and Sons.—A horizontal cylinder, fitted centrally in the steam-dome over the fire-box; the boiler covered with dry hair, felt, and wood, and the feed-water heated in the smoke-box.

Tuxford and Sons.—No. 1: a vertical cylinder, and the machinery neatly fitted in a case at the end of the boiler, with folding-doors to lock up all when required. Their No. 2 engine was similarly constructed, but with an oscillating cylinder.

Clayton and Co.—Neatly arranged, good working engine, with an external horizontal cylinder; now (1853) enclosed in steam.

Garrett and Sons.—Light, strong, portable engines, with an external horizontal cylinder.

Barrett and Co.—External horizontal cylinder, large boiler, and expansive link-valve motion.

Cabron.—Strong, heavy engine, with indifferently arranged machinery.

Butlin.—Workmanship moderate, and machinery of simple design.

Burrell.—Machinery simply arranged, and fair workmanship.

Hensman and Son.—The workmanship moderately good, but the boiler too small.

Roe and Co.—Too much cast iron used, with inferior workmanship and arrangements.

PRACTICAL RESULTS OF THE DYNAMIC TRIALS.

Maker.	Horse-power.	Time of getting up Steam.	Coals used in getting up Steam.	Coals used per H.P. per Hour.	Coals used per Hour of Hornsby's Engine.	Coals used per Hour Difference.
	No.	Men.	lbs.	lbs.	Per cent.	Per cent.
Hornsby & Son	6	49	35·23	6·73	100·0	
Tuxford & Son	6	53	56·68	7·46	110·8	10·8
Clayton & Co. .	6	32	35·40	8·63	128·2	18·2
Garrett & Sons	5	42	26·50	8·65	128·5	18·5
Barrett & Co. .	4·5	26	25·56	9·20	136·7	36·7
Tuxford & Son	4	41·5	35·60	10·85	161·2	61·2
Cabron . . .	9	44	52·00	12·48	185·4	85·4
Burrell . . .	6	28	35·00	13·10	194·6	94·6
Butlin . . .	4·5	50	42·00	14·71	218·4	118·5
Hensman & Son	4	33	29·00	18·75	278·6	178·6
Roe & Co. . .	4	83	75·20	25·8	383·3	283·3

The horse-power was measured by means of a Prony's brake, on the plan adopted by the Royal Agricultural Society.

Steam-Ploughing.—Amongst the first public trials of steam-ploughing was that made by Mr. Heathcote, M.P., on Lochar Moss, at the Scottish Highland Agricultural Society's Dumfries Meeting in 1836; and, more lately, Lord Willoughby d'Eresby most commendably persevered to reduce steam-ploughing to practice. Since that epoch, the industry of ploughing by steam has been enormously developed.

Conclusion.—In these few pages we have sought to compress an illustrated chronological chart of the principal chiefs, and progress of the steam family for upwards of 2,000 years. Distinguished, however, as it has become, its founder is unknown in the annals of heraldry. Of its two branches we have just seen how far the rotatory has been left in the rear by the reciprocatory branch, which has performed all the mighty deeds of modern times, by the combined forces of caloric, or heat and water. We may form some faint idea of the anxious hope and fear of each succeeding genius before his conceptions were clothed in mental or material form—the parental grief or joy as each child expired in infancy or arrived at manhood and fame. The scientific knowledge of such men as Desaguliers, Emerson, Smeaton, Black, Robertson, and others were all brought to bear on the progress of the reciprocatory steam-engine. It also embraces the material leading inventions of the loaded safety-valve, piston and cylinder of the ancients; the tubular boiler and steelyard safety-valve of Papin, a French physician; the condensation vacuum and gauge-cocks of Savary, an English miner; of the beam, boiler-pump, injection-pump, and vacuum below the piston of Newcomen, an English blacksmith; the hand-gear of Potter, an English peasant boy; the fly-wheel of Fitzgerald, an Irish professor; the condenser air-pump, double action, parallel motion, and governor of Watt, a Scottish mechanic; the crank motion of Pickard, an English mechanic; the metallic piston of Cartwright, an English dissenting clergyman; the oscillatory cylinder, eccentric motion, and slide-valve of Murdock, a Scottish mechanic; and the double cylinder of Hornblower, an English mechanic. From these inventors' inventions, modern engineers select at pleasure to construct an efficient engine for the duty to be done.

The first modern engine was Watt's, a Scottish mechanic; the first modern locomotive engine was Trevitheck's, an English mechanic; and the first modern steamboat was Symington's, a Scottish mechanic. The first regular river steamboat was Fulton's, an American mechanic; the first ocean steam voyage was made by Bell, a Scottish engineer. The most economical engines of the present day are constructed by Cornish mechanics; and the first locomotive was Cugnot's, a French engineer.

The amount of intellectual toil concentrated in a modern reciprocatory engine will therefore be obvious, as also that the principal inventions and combinations are those of working mechanics, who have nearly all died in poverty and distress.

We have now arrived at the locomotive epoch. Since 1822, the locomotive power of the reciprocating steam-engine forms one of the most remarkable events of the age. For ocean locomotion, the varieties of the stationary engine are used, but with their cylinders shortened and of larger diameter to suit the hold of the ships. The beam was replaced by one on each side of the cylinder, connected together by a cross-piece, into which the piston-rod was fitted; and these have been superseded by direct-acting engines, in which the beams or side levers are dispensed with. Oscillating engines are also employed in steamboats. Boilers are made of such forms as to suit the vessels; but even on land, where space is no object, the forms of boilers have varied, and still vary much. Watt's waggon class has lost ground from its weak form. Woolfe's, as improved by Galloway, and Evans's, as adopted by Trevitheck and the Cornish engineers, maintain a high reputation. Alban's improved tubular boiler enjoys a good name in Germany, and the locomotive tubular-flued boiler is also used for fixed engines. The railway locomotive engine is self-contained, and takes a form of its own adapted to its special duties, which are explained and illustrated in a separate treatise.

CHAPTER II.

GASES—THEIR GENERAL PROPERTIES.

Gases are divided into two classes—permanent gases and vapours. The former were originally so called, under the impression that they existed permanently in the gaseous state, and could not possibly be reduced to the liquid form; while those which could be so reduced, and could be reconverted to the state of gas, were called vapours. It has, however, been shown by Sir Humphrey Davy and Mr. Faraday, that, by the conjoined effects of great pressure and of a high degree of cold, most of the permanent gases may be liquified. The undermentioned, on the contrary, still retained the gaseous state at the annexed temperatures and pressures:—

Hydrogen, at	—166	degrees Fahr., and	27	atmospheres.
Oxygen,	—166	„	27	„
Do.	—140	„	58·5	„
Nitrogen,	—166	„	50	„
Nitric oxide,	—166	„	50	„
Carbonic oxide,	—166	„	40	„
Coal gas	—166	„	32	„

Several of the gases which have been liquefied are further capable of being reduced to the solid state. Thus, sulphurous acid becomes solidified at —105°; sulphuretted hydrogen at —122°; carbonic acid at —72°; ammonia at —103°. The difference, then, between the permanent gases and vapours is merely one of degree, and depends upon the temperature at which the change from the fluid to the gaseous state occurs. Those which exist in the fluid state under ordinary temperatures and pressures are called vapours; those which require strong pressure and extremely low temperature to reduce them to the liquid form are called permanent gases.

The influence of temperature on the expansion of permanent gases under constant pressure is such, that, for equal increments of temperature, the increments of volume by expansion are also equal, and they are nearly the same for different gases. The expansion of air by increase of temperature may be assumed to represent that of other gases; and, it may be added, the most exact measure of real temperature is to be found in the expansion of air or any other perfect gas. By real or absolute temperature is signified the measure of the whole of the heat of a body; and at the absolute zero-point of the scale, all gases would cease to have elasticity or molecular motion. As the expansion of air under constant pressure is found experimentally to be uniform for uniform increments of temperature, it is inferred, conversely, that it would contract uniformly under uniform reduction of temperature, until on arriving at a temperature 461° below zero of Farenheit's scale, or exactly —461·2°, the air would be in a state of collapse, without appreciable elasticity. This point has, therefore, been adopted as that of absolute zero, standing at the foot of the natural scale of temperature. For illustration, let a volume of air, 673 cubic inches in bulk, at a temperature of 212° Fahr., be confined at a constant pressure in a cylinder, under a piston movable without friction. If the gas be cooled 10°, the piston will descend through 10 cubic inches; if cooled 100°, the piston will descend, and the air will contract, through 100 cubic inches; and so on, in the same ratio; so that, by lowering the temperature 673°, the air would not possess any appreciable volume; and 673° — 212° = 461° below the artificial zero of Fahr. would, therefore, be arrived at as the point of absolute zero.

Again, if a given weight of air at 0° Fahr. be raised in temperature to 461° under a constant pressure, its volume will be doubled by expansion; and if heated to 461 × 2 = 922°, its volume will be trebled; in short, for every increment of one degree of temperature, its volume will be enlarged by equal increments uniformly $\frac{1}{461}$ part of the volume at 0°.

The following, then, are the established relations of the properties of permanent gases:—

With a constant temperature, the pressure varies simply as the density, or inversely as the volume. This is known as Boyle's or Marriotte's law.

With a constant pressure, expansion is uniform under a uniform accession of heat or rise of temperature, at the rate of $\frac{1}{461}$ part of the volume at 0° Fahr. for each degree of heat. If, then, 461° be added to the indicated temperature by Fahrenheit's scale, the sum, or absolute temperature, will vary directly as the total volume, expanding or contracting, and inversely as the density. This is known as the law of Gay-Lussac.

With a constant volume, or density, the increase of pressure is uniformly at the rate of $\frac{1}{461}$ part of the pressure at 0° Fahr. for each degree of temperature acquired. Adding 461° to the indicated temperature, the sum, or absolute temperature, varies directly as the total pressure.

In brief, 1st, the pressure varies inversely as the volume when the temperature is constant; 2nd, the volume varies as the absolute temperature when the pressure is constant; 3rd, the pressure varies as the absolute temperature when the volume is constant.

The foregoing enunciation of the relations of temperature, pressure, and density should be qualified by the remark, that the more easily condensable gases, as they approach the liquefying point, become sensibly more compressible than air; and that they do not strictly conform to the relations of pressure and volume above recited for permanent gases. It has been found that, as far as 100 atmospheres, oxygen, nitrogen, hydrogen, nitric oxide, and carbonic oxide follow the same law of compression as atmospheric air, these being amongst the incondensable gases; and that sulphurous acid, ammoniacal gas, carbonic acid, and protoxide of nitrogen—proved to be condensable—commence to be sensibly more compressible than air when they have been reduced to one-third or one-fourth of their original volume. Carbonic acid, for example, in place of following the simple ratio of the pressure and density for a constant temperature, increases in density, or, which is the same thing, diminishes in volume, in a greater ratio than the pressure, as indicated in the following Table, No. I., showing in the third column the volume of carbonic acid under increasing pressures, compared with that of air, which is expressed by unity :—

TABLE No. I.

SHOWING THE COMPRESSIBILITY OF CARBONIC ACID, COMPARED WITH THAT OF AIR. TEMPERATURE, 10° CENTIGRADE, OR 50° FAHRENHEIT.

Pressure.	Volume of Air under the given Pressure. (Volume under One Atmosphere = 1,000.)	Volume of Carbonic Acid under the given Pressure.
Atmospheres.		
1	1,000	1,000
2	500	500
4	250	250
5	200	198
6·67	150	147
10	100	93
15·38	65	61
20	50	46
25	40	35
33·3	30	24
40	25	18·5
45	22·2	liquified.

The Table shows that carbonic acid sensibly follows the law of compression of a perfect gas, as far as four atmospheres, when its volume becomes one-fourth of that under one atmosphere. Under five atmospheres, it sensibly begins to shrink, until, under forty atmospheres, it occupies less than three-fourths of the volume of air. Under forty-five atmospheres, it is liquefied.

The accelerated diminution of volume, or incipient condensation, characteristic of carbonic acid and other condensable gases, in approaching the point of liquefaction, foretells the approaching change. It is, nevertheless, established that all gases, at some distance from the point of maximum density for the pressure, substantially follow the law of Boyle, according to which the pressure and the density vary directly as to each other, when the temperature is constant. With this explanation, they rank as perfect gases.

CHAPTER III.

AIR AND PRESSURE GAUGES.

UNTIL near the middle of the seventeenth century it was not even suspected that the air possessed either weight or elastic force. Pumps, being an earlier invention of Ctesibus, had come into general use for raising water, and practical men had noted the fact that water rose far above its natural level in the pump-tube when the working valve, or bucket, had withdrawn the air from that part of the tube. Philosophers explained this as a proof that nature abhorred a vacuum, which caused the water to fill the vacuum in the pump-tube, and in fixing them this was taken advantage of by placing the working valves where most convenient. However, a pump having been erected at Florence for the Duke of Tuscany, it failed to raise any water, and its failure was a very unexpected result. It was then ascertained that the water was above 33 feet distant from the pump-valve, and only rose to about that height, but not within the scope of action of the pump, hence the cause of the failure was apparent, but not so the limit thus assigned to Nature's abhorrence of a vacuum. Galileo was consulted, but was unable to give any valid reason for this limit at the time. Reflection, however, led him to conclude that the air had weight, and that the weight pressing on the water caused it to rise. Following out this reasoning, his pupil Torricelli had the honour to construct the first barometer, and to determine by experiment the relative weight and pressure of air.

As barometers are applied to measure the pressure of steam as well as that of air, a description of them will be instructive.

Fig. 58 or 59 is a glass tube about 36 inches long, closed at one end, which Torricelli filled with mercury, carefully excluding the air. Then applying his finger to the open end, he inverted the tube with its open end in a cup containing both water and mercury. He then withdrew his finger while the tube end was immersed amongst the mercury, when it flowed out until it became stationary at a height of about thirty inches. When the end of the tube was raised out of the mercury, and open to the water, the mercury flowed out, whilst the water rushed in to the top of the tube, showing that it would have risen still higher, had the tube been longer. These simple yet beautifully important experiments clearly demonstrated that the pressure of the air was equal to the pressure of a column of mercury thirty inches high, or to a column of water of an equal pressure.

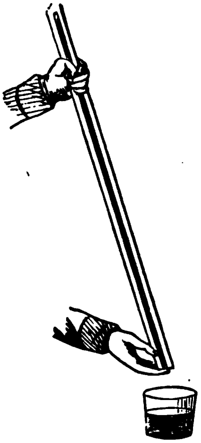
Fig. 58.

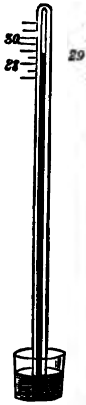

Fig. 59.

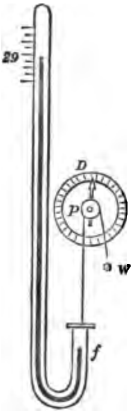

Fig. 60.

The specific weight of mercury varies according to its purity and temperature, but in ordinary circumstances it is about 13·6 times heavier than water, hence the height of a column of water equal to the weight of a column of mercury 30 inches high would be 30 × 13·6 ÷ 12 in. = 34 feet, which water would rise in a perfect vacuum by the pressure of the air on its surface. This, therefore, proved that the water would rise to a height in the pump-tube more or less near to 34 feet, as the vacuum was more or less perfect, but beyond 34 feet the pressure of the air would fail to raise the water, thereby solving the pump problem in the most satisfactory manner. Since a cubic foot of water is nearly and usually taken as 1000 ounces avoirdupois, a cubic foot of mercury would be 1000 × 13·6 = 13,600 ounces, and one inch of mercury would be 13,600 ÷ 1728 = 7·87 ounces, therefore 30 × 7·87 ÷ 16 ounces = 14·75 lbs. as the elastic force of the air at the level of the sea. In round numbers it is usual to consider the pressure of the air as equal to 15 lbs. on each square inch, which is called the pressure of one atmosphere, 30 lbs. being that of two atmospheres, 45 lbs. that of three atmospheres, and so on with each additional 15 lbs. It will illustrate the pressure of elastic fluids in every direction, when it is stated that the pressure of air on the body of an average-sized man amounts to about 15 tons, which of course would instantly crush him to the earth, were it not counteracted by its equality of pressure in every direction, upwards, sidewards, downwards, internally, and externally. Its weight is 772·4 times lighter than water, having a specific gravity of ·001293. The elastic force of air on a square foot of surface would amount to 144 × 14·75 lbs. = 2124 lbs., but the weight of 144 cubic inches would only be ·00669 lbs., or nearly 31·72 times less weight than pressure. This greater pressure is due to the superincumbent column of air estimated by some as from 45 to 50 miles high, but by others as not even so high as 40 miles.

Air has, therefore, both weight and force pressing in every direction, in the ratio of 2124 lbs. per square foot of surface, yet in it we live, move, and breathe, as if it had neither weight nor force. Many attempts have been made to bring the elastic force of the atmosphere into mechanical use, like steam. The Croydon and South Devon Atmospheric Railways, now abandoned, and Prosser's compressed-air engine are recent instances of these efforts, but as yet they have been unable to compete with steam in portability and economy.

Fig. 60 is the modern form of barometer for halls, where the float is suspended by a fine line over the small pulley *p*, and balanced by a weight *w*; and as the pulley is moved by the action of the float *f*, the indications by the index *i* are read off on a large dial, D.

As we ascend the pressure of the air diminishes, and by this means the barometer is employed to measure the heights of mountains and other elevated places with considerable accuracy, by the fall of the mercury. Pascal first applied it to this purpose; but as the pressure of the air diminishes by increase of temperature, as well as by increase of height, and its density increases by cold, it requires a scale graduated accordingly. For example, a decrease of 1° of temperature increases the density or pressure of the air ·0033 inches of mercury between the limits of 32° and 52°; but from 32° down to zero the mercury falls ·0034 for each difference of 1° of temperature. At an elevation of 500 feet the mercury falls half an inch; but at 31 times 500 ft. high, it only falls 28 half-inches, and at 41 times 500 ft. high only 36 half-inches.

The following rule gives the heights of places nearly:—

Multiply the difference of the logarithms of the respective barometric heights by 6000 for the height above the level of the sea in feet.

Ex.—Required the elevation of a hill at whose base the height of the mercury was 30 inches and at the top 28 inches,

$$\log.\ 30 = 477121$$
$$\log.\ 28 = \underline{447158}$$

Difference = 029963 × 6000 = 1797·78 feet as the height required.

To obtain a more portable and sensitive barometer for such measurements than the mercurial one, a vacuum barometer of ingenious yet comparatively complicated construction has been brought to considerable perfection in France, since M. Conte first introduced it. As now improved by Mr. Dent, of London, it is a portable, and as it may be an agreeable companion to railway travellers for determining the comparative elevation of the countries or railways that they travel over, we annex a brief description of its principle of action.

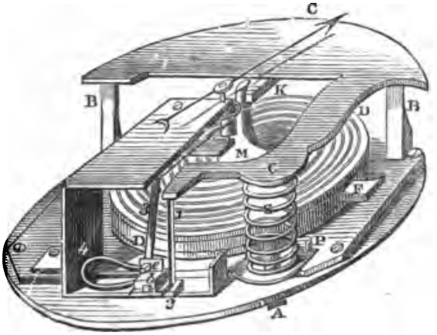

Fig. 61.—Dent's Aneroid Barometer.

The same letters apply to all the figures.

In Fig. 61 D D is the vacuum vase; M, the socket for distending it. C C is a lever, to one end of which is attached the vertical rod, 1, which connects it with the levers, 2, 3. These levers are connected by a bowpiece, 4, and the whole are regulated for the index to move over a space corresponding to the scale of a mercurial barometer. The end of lever 3 is connected to the axis, on which the hand or index is fixed by a piece of fine watch-chain. A spiral spring regulates the hand, and the force of the levers in obedience to the indication

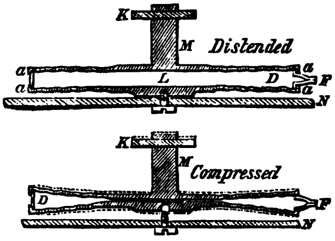

Fig. 63.

of the vacuum vase D D, as distended Fig. 62, and compressed Fig. 63, by the weight of the atmosphere.

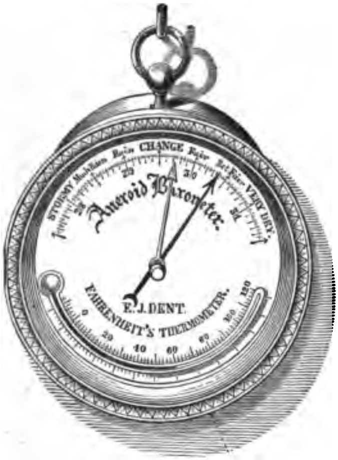

Fig. 64.—Front Elevation.

Fig. 64 exhibits a front view of this ingenious instrument. The indication-hand, shown in outline, is to be set exactly over the balanced hand at the commencement of any experiment. The movement of the balanced hand to either the right or the left will then indicate the increase or decrease of the atmospheric pressure.

Fig. 65 will explain the principle of action. C C is a lever of the second order, similar to a locomotive safety-valve lever, which has its fulcrum at B and its force measured by the spiral spring S. The vacuum vase is attached to the lever C C at D, one-seventh of the distance between B and S. It is 2½ inches diameter, having about 72 lbs. pressure on its area, whose action on the lever C at D, as represented by the arrows, is 6 times increased on the spring S, the lever being as 6 to 1, or 7 parts in all. This it is obvious renders the least variation of pressure quite sensible by the spring when the friction of the parts is reduced to

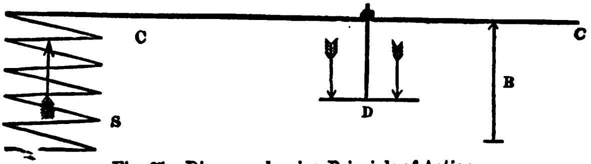

Fig. 65.—Diagram showing Principle of Action.

a minimum. In Dent's the motion of the index-hand one-tenth of an inch indicates an alteration of either 85 feet higher or lower, as the case may be. The action of a barometer is therefore regulated by the weight of the air, which is heaviest during serene settled or frosty weather, or when contrary easterly or northerly winds blow it towards any locality. It is lightest when saturated with steam to the rainy point, or when contrary winds blow it away from any locality. In northerly climates the variation is greatest, and least within the tropics.

Mercurial Gauges for Steam-Engines.

These useful appendages to the steam-engine being either barometrical or thermometrical, this seems the proper place to describe them. Where the length is not a consideration the barometric ones act well, but thermometric ones cannot be depended upon generally.

Fig. 66.

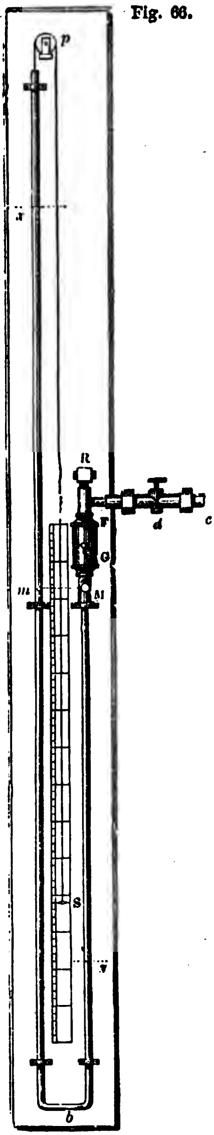

Fig. 66 is one of the forms in which mercury is employed to measure the pressure of steam when it is only a few pounds more pressure than that of the atmosphere. Steam is admitted from the boiler by the pipe *c*, and presses the mercury up the iron syphon tube M, *b*, *m*. Each 2 inches of rise is nearly equal to 1 lb. pressure above the atmosphere, which has access to the top of the mercury by the open end of the tube. A line from the float in this tube passes over the pulley p, and is attached to the index S, to show the variation of pressure on the annexed scale. Gauges of this barometric form require to have a length equal to 2 inches for each pound of pressure, which makes them inconvenient at high pressures. It is thus constructed: M, *m*, R, are three openings fitted with suitable screws. These are taken out, and mercury poured in until it shows itself at M, *m*, in each leg of the syphon, when these two holes are screwed up. Some water is then poured in at R, which is then also screwed up, and the instrument ready for use. The water prevents the heat of the steam oxidizing the mercury, which is found to injure its expansive action, and render its indications erroneous in thermometrical steam gauges.

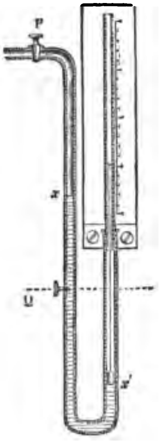

Fig. 67.

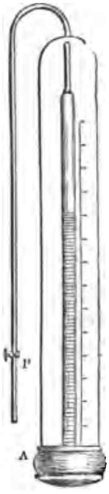

Fig. 68.

Fig. 67 is a different form, where the mercury is all contained in the tube x x, which has one end connected to the boiler by the pipe P and the other end open to the atmosphere, the indications being given off on the attached scale of parts.

Fig. 68 is another form of mercurial gauge for condensers. A, a cup filled with mercury, in which the barometric tube is immersed, having the other end bent in the syphon form, and connected with the condenser of a low-pressure engine. On the cock P being opened, the pressure of the air on the mercury in the cup causes it to rise and indicate, on the scale of parts, the comparative vacuum produced in and power gained from the condenser.

In all these gauges the pressures indicated are the differences between the atmospheric pressure and the pressure in the boiler or in the condenser. In condensers the pressure will be less than the atmosphere by 2 inches for each pound pressure. In the boiler, the pressure will be greater than the atmosphere by 2 inches for each pound. So that a rise of 8 inches in the boiler gauge indicates steam of 4 lbs. pressure above the atmosphere, or 19 lbs. gross pressure, and a rise of 24 or 26 inches in the condenser gauge shows that a pressure of 12 or 13 lbs. has been added to the 4 lbs. pressure, making a working pressure of 16 or 17 lbs. per square inch from an apparent pressure of only 4 lbs.

Air Gauge.

Since the preceding gauges require a length of 2 inches of mercury for each pound of pressure, they are inapplicable to pressures of 60 or 100 lbs. on locomotive boilers. In place of leaving the mercury exposed to the air at one end, and to the steam at the other end, air is confined in a Torricellian tube, closed at the upper end, and resting in a cup of mercury at the lower end, on which the force of the steam acts to compress the column of air, which then becomes the measure of the force of steam.

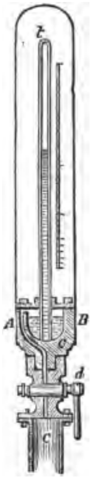

Fig. 69.

Fig. 69 will show their construction. *t t* the glass tube containing air, immersed in the cup A B of mercury, which rises to the level or pressure balanced by the mercury in the cup and the air in the tube, for the zero of the gauge. The volume of a given quantity of air being inversely as the space it occupies, a scale—starting at the gauge zero—is adjusted to this established law, to show the force of the steam by the diminished volume of the confined air. For instance, if the pressure be 20 lbs. and increased to 40 lbs., the volume of air would be reduced one-half, and at 60 lbs. to one-third, the volume at 20 lbs., as will be further illustrated under the head of Expansive Force of Elastic Fluids. On steam being admitted by the stopcock *d* it presses upon the mercury in A B, which raises and compresses the air in the tube and indicates the force on the scale. Gauges of this class were employed by both the French Academy and Franklin Institutes in their valuable experiments on steam.

When carefully made and adjusted they are valuable instruments. On locomotive engines the passing current keeps the confined air from heating, which requires to be guarded against, and if the scale is correctly adjusted the indications would be accordingly.

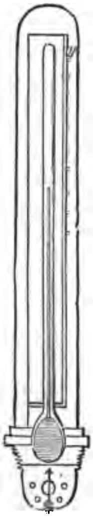

Fig. 70.

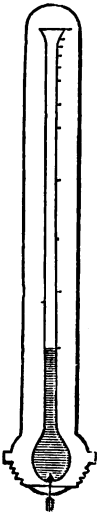

Fig. 71.

Fig. 70 is another form of this useful gauge, where very small holes in the bottom of the bulbous part of the tube admit the direct action of the steam on the mercury, whilst the reservoir at the top gives a larger volume of air to act against, with less risk of error.

When steam is freely admitted to act on mercury for a length of time, the mercury is found to deteriorate; and the loss of any portion of it from the tube or cup would affect the accuracy of the scale. Mr. Davies of Leeds states that he has, by using a larger column of mercury, greatly improved the accuracy and durability of mercurial steam gauges.

Thermometric gauges (Fig. 71) are similarly constructed to those already described for measuring heat by, and are designed to give the force of steam from its temperature. They have not yet, however, been successful for accuracy of indications. If the heat communicated to the bulb is partly lost in the ascent of the mercury, the upper portion would not equally expand with the lower portion ; or if the bulb is ever so slightly compressed by the force of the steam, the indications in each instance would be incorrect.

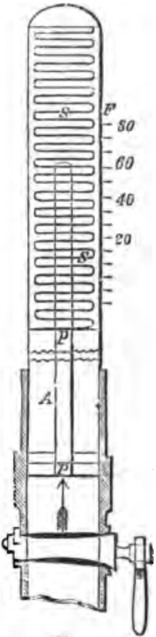

Fig. 72.

The changing pressure in locomotive boilers from their small steam space and rapid consumption renders slight variations of temperature easily effected by atmospheric influence or other disturbing causes. If the tube were of greater length and surrounded by an atmosphere of the same temperature as is in the boiler, thermometric gauges might be depended upon, but for ordinary locomotive purposes there are several impediments to their successful application.

Besides mercurial gauges, spring gauges have been made of the form shown in Fig. 72, which is a small cylinder exactly one square inch area, of which piston P is made to compress the spiral spring S S, according to the force of the steam on the piston, and an index attached to the piston rod shows the force on a scale F adjusted to the spring. This is, in fact, Watt's indicator applied as a permanent gauge.

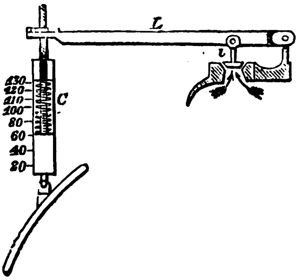

Fig. 73.

Salter's well-known spring balance, Fig. 73, also measures the pressure by the upward force of the steam on the safety valve *l*, compressing a double spiral spring within the cylindrical case C, by the action of the lever L, and showing the force on a scale of pounds.

CHAPTER IV

WATER.

Composition of Water.

To understand the nature of steam, it is desirable to possess a knowledge of its component parts. Familiar as are these components, water and heat, yet each of them has formed the subject of elaborate researches, and each of them yet excites interest; the water, as to its composition, and the heat as to its nature.

In its ordinary state, water is a fluid covering a very large portion of the globe, performing most important duties. It is not only abundant as a fluid, but, united with other bodies, it forms a large proportion of animal and vegetable matter. Analysts tell us that potatoes contain 75 per cent., turnips 90 per cent., a beef steak 80 per cent., and a man 75 per cent. of water. Chemically, they tell us that, a man of 10 stone would be made up of 105 lbs. of water and 35 lbs. of carbon and nitrogen, and that $\frac{5}{8}$ths of his daily food is water.

It has been general, since Watt's discovery of the composition of water, to define it as consisting of one volume of oxygen and two volumes of hydrogen, or by weight 1 part of hydrogen and 8 parts of oxygen, the specific gravity of the latter being 16 times that of the former.

It is usual to prove this theory of the composition of water by burning or exploding these two gases in a glass vessel, when water is deposited equal in weight to that of the decomposed gases. It has, however, been suggested that the force required to compress these gases into water must also find some electrical agent in them so as to produce their marked compression in volume. For water is nearly 30 times heavier than oxygen, 478 times heavier than hydrogen, and 34 times heavier than air.

Expansive Power of Water.

Water is at its greatest density at 39·1° Fah., but does not become solid until 32°, when its expansive force is exhibited in the disintegration of rocks, bursting of pipes, or fracturing other bodies in which it may be confined. The following trials were made in the Arsenal at Warsaw, in 1828-9, for the purpose of ascertaining the expansive force of water in a state of freezing.

Cast-iron howitzer shells, 6 in. 8 lines diameter, having a thickness of metal 1 in. 2 lines, and an orifice or opening of 1 in. 2 lines diameter, were employed. One of these shells, having a capacity of 46·29 cubic in., was filled with water at 40° Fah., and with the orifice open exposed to the atmosphere at 21° Fah. In two hours a column of ice 2 in. 2 lines long was projected from the opening, which was the greatest effort made, and gave an expansive force of 2·31 cub. in., or about $\frac{1}{20}$th part of the whole volume, or 5 per cent.

A second shell was filled, and the orifice closed with a piece of wood driven into it. It was then exposed as before, when the plug was expelled, and ice occupied its place.

A third shell was filled, and the orifice closed with an iron screw, having through it a hole of 3 lines diameter. After two hours' exposure the shell was burst into two unequal parts, the smaller being thrown 10 feet, and the larger part thrown 1 foot from the spot it was placed upon. The ice had formed only 6 lines thick, the remainder of the water being still fluid. A fourth shell was filled, plugged, and exposed at 28° in a similar manner, with a hole of 6 lines diameter, and also burst in two parts, one of them being thrown a distance of 4 feet. The ice was 13 lines thick, the rest fluid. A fifth shell was filled, plugged up solidly, and exposed at 28°, when it burst as before, and the smallest piece was thrown a distance of one foot. The thickness of the ice was only 5 lines.

These experiments convey some definite idea of the expansive power of water in a freezing state; the power is supposed to be derived from the re-arrangement of the crystallizing particles in angles of 60° or 120° to each other, requiring more space than when in a fluid state, and thus resisting confinement.

Forcing Power of Water.

Being almost incompressible, water is made to develop immense power in Bramah's hydraulic presses, whereby the strength of cables, anchors, iron, and other materials is tested, goods packed, and other operations performed requiring great force.

A remarkable performance in this field was the lifting of the Conway and Britannia tubular bridges 100 ft. high into their places. The weight of the largest tube being about 1800 tons, and one end lifted at a time, gave about 900 tons as the weight to be raised at once. This was done by a strong cast-iron cylinder, 11 in. thick, with a solid piston, or ram 20 in. in diameter and 6 ft. stroke, working through a water-tight stuffing-box or gland. Into this cylinder the water was forced through a half-inch pipe by a pump of $1\frac{1}{16}$ in. diameter worked by a 40-horse steam-engine. The power would therefore be as the areas of the ram and pump were to each other, or as 1 to 355. The pressure on the ram would then be 900 tons, or

$$\frac{900 \times 2240 \text{ (lbs. water)}}{314{\cdot}16 \text{ (area of piston)}} = 6417 \text{ lbs pressure for}$$

each square inch of the head of the ram.* The action may be thus explained: water is slowly forced into the cylinder by the pump, and being very nearly incompressible, as soon as the vacant space in the cylinder is filled, it gradually impels the ram outwards, with a force measured by the resistance against the external end of the ram, and limited by the strength of the cylinder and power of the pump to force in the water.

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* For an interesting description of these bridges, see "Rudimentary Treatise on Iron Girder Bridges."

Weight and Measure of Water.

Water is the standard of comparison of the weights or gravities of other liquids and of solids. At 39·1° Fah. a cubic foot of water weighs 998·8 ounces avoidupois; but for facility in calculations the weight is generally taken as 1000 ounces, and the imperial gallon is fixed at 160 ounces, or 10 lbs. avoirdupois of distilled water. In pounds, the weight of a cubic foot of water is taken as 62·4 lbs., or as 62½ lbs., and the cubic contents in feet of any water-tank or boiler multiplied by 62½ gives the weight of water in lbs. avoirdupois required to fill it, and this divided by 10 give the number of gallons. Thus, if the water-space in a boiler be 60 cubic ft. it will contain 3750 lbs. or 375 gallons of water, for

$$60 \times 62{\cdot}5 = 3750 \text{ lbs. and } \frac{3750}{10} = 375 \text{ gallons.}$$

The standard fixed by Parliament for the Imperial gallon is 10 lbs. avoirdupois of water, at a temperature of 62° Fah. There are 62·355 gallons of water in one cubic foot. The following Table gives the weight of a gallon of water at each degree of temperature from 32° to 212°:—

TABLE No. II.

WEIGHT OF ONE GALLON OF WATER, AT TEMPERATURES FROM 32° TO 212°.

Temperature.	Weight.	Temperature.	Weight.	Temperature.	Weight.
Fah.	lbs.	Fah.	lbs.	Fah.	lbs.
32°	10·0101	90°	9·9655	155°	9·7987
35	10·0103	95	9·9564	160	9·7810
39·1	10·0112	100	9·9466	165	9·7570
40	10·0112	105	9·9366	170	9·7475
45	10·0103	110	9·9222	175	9·7212
50	10·0087	115	9·9126	180	9·7105
55	10·0063	120	9·8965	185	9·6913
60	10·0053	125	9·8870	190	9·6720
62	10·0000	130	9·8725	195	9·6543
65	9·9961	135	9·8585	200	9·6352
70	9·9912	140	9·8437	205	9·6111
75	9·9862	145	9·8293	210	9·5935
80	9·9812	150	9·8150	212	9·5839
85	9·9713				

This shows that from the point of greatest density (39°·1) water expands both ways, becoming gradually lighter per gallon, down to the freezing point and upwards to the boiling point. Sea-water has its greatest density at the freezing point. Its density at 32° Far. is 64·05 pounds per cubic foot.

For calculating the quantities of water contained in either cylindrical or rectangular vessels, the following exponents of the relative weights and measures of water at its ordinary temperature will be useful:—

For Cylindrical Vessels or Boilers.

Water.

Cyl. in.		Diam.	Length.	Lbs. avr.		Imp. gal.
1	or	1 ×	1 =	·02842	or	·00284
12	or	1 ×	12 =	·341	or	·034
1 728	or	1 cyl. ft. =		49·1	or	4·91
		2·282 cyl. ft. =		1 cwt.	or	11·2
		45·64 „ =		1 ton	or	224·
		352·97 cyl. in. =		1		gal.
		1·273 „ =		1		cubic in.
		1· „ =		·7854 „		

To find the capacity of any other cylinder, multiply the square of its diameter by its length, and the product by the exponent of the unit of the feet or inches in which the dimensions may be taken. For elliptical vessels or boilers multiply the longest by the shortest diameter, and by the length for the capacity in cylindrical inches, and the product by the required exponent.

For concentric spaces add together the inner and outer diameters, and multiply the sum by the difference of these diameters, and by the length for the capacity in cylindrical inches, which being multiplied by the tabular exponent will give the required quantity.

Spherical Vessels.

		lbs. avr.		gal. imp.	
A globe of water	1 in. diam. =	·0189	or	·001888,	or 1 spherical inch.
„	12 „ =	32·75	or	3·263,	or 1 spherical foot.

To find the capacity of any other sphere multiply the cube of its diameter by the required exponent of unity of the dimensions taken in feet or inches.

Rectangular and Cubical Vessels.

Water.

Cub. in.	Sq. length.	Lbs. avr.		Imp. gal.
1 or 1	× 1=	·03617	or	·00361
12 or 1	× 12=	·434	or	·0434
1,728 or 1	cub. ft. =	62·5	or	6·25
1·8	cub. ft. =	1 cwt.	or	11·2
35·84	„ =	1 ton	or	224·
277·274	cub.in. =	1 imp. gal.		
·1	„ =	1·273 cyl. in.		
·7854	„ =	1· „		

The cubical contents of any other rectangular vessel may be found by multiplying the length, width, and depth together, and their product by the requisite exponent.

TABLE No. III.

AREAS OF SEGMENTS OF A CIRCLE; DIAMETER = 1.

Hght.	Area Seg.	Hght.	Area Seg.	Hght.	Area Seg.	Hght.	Area Seg.	Hght.	Area Seg.
·001	·000042	·048	·013818	·095	·037909	·142	·068225	·189	·103116
·002	·000119	·049	·014247	·096	·038496	·143	·068924	·190	·103900
·003	·000219	·050	·014681	·097	·039087	·144	·069625	·191	·104685
·004	·000337	·051	·015119	·098	·039680	·145	·070328	·192	·105472
·005	·000470	·052	·015561	·099	·040276	·146	·071083	·193	·106261
·006	·000618	·053	·016007	·100	·040875	·147	·071741	·194	·107051
·007	·000779	·054	·016457	·101	·041476	·148	·072450	·195	·107842
·008	·000951	·055	·016911	·102	·042080	·149	·073161	·196	·108636
·009	·001135	·056	·017369	·103	·042687	·150	·073874	·197	·109430
·010	·001329	·057	·017831	·104	·043296	·151	·074589	·198	·110226
·011	·001533	·058	·018296	·105	·043908	·152	·075306	·199	·111024
·012	·001746	·059	·018766	·106	·044522	·153	·076026	·200	·111823
·013	·001968	·060	·019239	·107	·045139	·154	·076746	·201	·112624
·014	·002199	·061	·019716	·108	·045759	·155	·077469	·202	·113426
·015	·002438	·062	·020196	·109	·046381	·156	·078194	·203	·114230
·016	·002685	·063	·020680	·110	·047005	·157	·078921	·204	·115035
·017	·002940	·064	·021168	·111	·047632	·158	·079649	·205	·115842
·018	·003202	·065	·021659	·112	·048262	·159	·080380	·206	·116650
·019	·003471	·066	·022154	·113	·048894	·160	·081112	·207	·117460
·020	·003748	·067	·022652	·114	·049528	·161	·081846	·208	·118271
·021	·004031	·068	·023154	·115	·050165	·162	·082582	·209	·110083
·022	·004322	·069	·023659	·116	·050804	·163	·083320	·210	·119897
·023	·004618	·070	·024168	·117	·051446	·164	·084059	·211	·120712
·024	·004921	·071	·024680	·118	·052090	·165	·084801	·212	·121529
·025	·005230	·072	·025195	·119	·052736	·166	·085544	·213	·122347
·026	·005546	·073	·025714	·120	·053385	·167	·086289	·214	·123167
·027	·005867	·074	·026236	·121	·054036	·168	·087036	·215	·123988
·028	·006194	·075	·026761	·122	·054689	·169	·087785	·216	·124810
·029	·006527	·076	·027289	·123	·055345	·170	·088535	·217	·125634
·030	·006865	·077	·027821	·124	·056003	·171	·089287	·218	·126459
·031	·007209	·078	·028356	·125	·056663	·172	·090041	·219	·127285
·032	·007558	·079	·028894	·126	·057326	·173	·090797	·220	·128113
·033	·007913	·080	·029435	·127	·057991	·174	·091554	·221	·128942
·034	·008273	·081	·029979	·128	·058658	·175	·092313	·222	·129773
·035	·008638	·082	·030526	·129	·059327	·176	·093074	·223	·130605
·036	·009008	·083	·031076	·130	·059999	·177	·093836	·224	·131438
·037	·009383	·084	·031629	·131	·060672	·178	·094601	·225	·132272
·038	·009763	·085	·032186	·132	·061348	·179	·095366	·226	·133108
·039	·010148	·086	·032745	·133	·062026	·180	·096134	·227	·133945
·040	·010537	·087	·033307	·134	·062707	·181	·096903	·228	·134784
·041	·010931	·088	·033872	·135	·063389	·182	·097674	·229	·135624
·042	·011330	·089	·034441	·136	·064074	·183	·098447	·230	·136465
·043	·011734	·090	·035011	·137	·064760	·184	·099221	·231	·137307
·044	·012142	·091	·035585	·138	·065449	·185	·099997	·232	·138150
·045	·012554	·092	·036162	·139	·066140	·186	·100774	·233	·138995
·046	·012971	·093	·036741	·140	·066833	·187	·101553	·234	·139841
·047	·013392	·094	·037323	·141	·067528	·188	·109334	·235	·140688

Hght.	Area Seg.	Hght.	Area Seg.	Hght.	Area Seg.	Hght.	Area Seg.	Hght.	Area Seg.
·236	·141537	·289	·188140	·342	·237369	·395	·288476	·448	·340793
·237	·142387	·290	·189047	·343	·238318	·396	·289453	·449	·341787
·238	·143238	·291	·189955	·344	·239268	·397	·290432	·450	·342782
·239	·144091	·292	·190864	·345	·240218	·398	·291411	·451	·343777
·240	·144944	·293	·191775	·346	·241169	·399	·292390	·452	·344752
·241	·145799	·294	·192684	·347	·242121	·400	·293369	·453	·345768
·242	·146655	·295	·193596	·348	·243074	·401	·294349	·454	·346764
·243	·147512	·296	·194509	·349	·244026	·402	·295330	·455	·347759
·244	·148371	·297	·195422	·350	·244980	·403	·296311	·456	·348755
·245	·149230	·298	·196337	·351	·245934	·404	·297292	·457	·349752
·246	·150091	·299	·197252	·352	·246889	·405	·298273	·458	·350748
·247	·150953	·300	·198168	·353	·247845	·406	·299255	·459	·351745
·248	·151816	·301	·199085	·354	·248801	·407	·300238	·460	·352742
·249	·152680	·302	·200003	·355	·249757	·408	·301220	·461	·353739
·250	·153546	·303	·200922	·356	·250715	·409	·302203	·462	·354736
·251	·154412	·304	·201841	·357	·251673	·410	·303187	·463	·355732
·252	·155280	·305	·202761	·358	·252631	·411	·304171	·464	·356730
·253	·156149	·306	·203683	·359	·253590	·412	·305155	·465	·357727
·254	·157019	·307	·204605	·360	·254550	·413	·306140	·466	·358725
·255	·157890	·308	·205527	·361	·255510	·414	·307125	·467	·359723
·256	·158762	·309	·206451	·362	·256471	·415	·308110	·468	·360721
·257	·159636	·310	·207376	·363	·257433	·416	·309095	·469	·361719
·258	·160510	·311	·208301	·364	·258395	·417	·310081	·470	·362717
·259	·161386	·312	·209227	·365	·259357	·418	·311068	·471	·363715
·260	·162263	·313	·210154	·366	·260320	·419	·312054	·472	·364713
·261	·163140	·314	·211082	·367	·261284	·420	·313041	·473	·365712
·262	·164019	·315	·212011	·368	·262248	·421	·314029	·474	·366710
·263	·164899	·316	·212940	·369	·263213	·422	·315016	·475	·367709
·264	·165780	·317	·213871	·370	·264178	·423	·316004	·476	·368708
·265	·166663	·318	·214802	·371	·265144	·424	·316992	·477	·369707
·266	·167546	·319	·215733	·372	·266111	·425	·317981	·478	·370706
·267	·168430	·320	·216666	·373	·267078	·426	·318970	·479	·371704
·268	·169315	·321	·217599	·374	·268045	·427	·319959	·480	·372704
·269	·170202	·322	·218533	·375	·269013	·428	·320948	·481	·373703
·270	·171089	·323	·219468	·376	·269982	·429	·321938	·482	·374702
·271	·171971	·324	·220404	·377	·270951	·430	·322928	·483	·375702
·272	·172867	·325	·221340	·378	·271920	·431	·323918	·484	·376702
·273	·173758	·326	·222277	·379	·272890	·432	·324909	·485	·377701
·274	·174649	·327	·223215	·380	·273861	·433	·325900	·486	·378701
·275	·175542	·328	·224154	·381	·274832	·434	·326892	·487	·379700
·276	·176435	·329	·225093	·382	·275803	·435	·327882	·488	·380700
·277	·177330	·330	·226033	·383	·276775	·436	·328874	·489	·381699
·278	·178225	·331	·226974	·384	·277748	·437	·329866	·490	·382699
·279	·179122	·332	·227915	·385	·278721	·438	·330858	·491	·383699
·280	·180019	·333	·228858	·386	·279694	·439	·331850	·492	·384699
·281	·180918	·334	·229801	·387	·280668	·440	·332843	·493	·385699
·282	·181817	·335	·230745	·388	·281642	·441	·333836	·494	·386699
·283	·182718	·336	·231689	·389	·282617	·442	·334829	·495	·387699
·284	·183619	·337	·232634	·390	·283592	·443	·335822	·496	·388699
·285	·184521	·338	·233580	·391	·284568	·444	·836816	·497	·389699
·286	·185425	·339	·234526	·392	·285544	·445	·337810	·498	·390699
·287	·186329	·340	·235473	·393	·286521	·446	·338804	·499	·391699
·288	·187234	·341	·236421	·394	·287498	·447	·339798	·500	·392699

PROBLEM.

To find the Area of a Segment of a Circle.

RULE.—Divide the height, or versed sine, by the diameter of the circle, and opposite the quotient in the column of heights in the annexed Table, No. 3, take out the area, in the column on the right hand, and multiply it by the square of the diameter, for the area of the segment.

EXAMPLE.—Required the area of a segment of a circle, of which the height is 9 inches and the diameter of the circle 58 inches.

$9 \div 58 = \cdot155$ and opposite $\cdot155 = \cdot07747 \times 58^2 = 261\cdot5$ sq. in. $\times 1\cdot273 = 331$ cubic inches, as the required area.

In calculating the separate contents of a cylindrical boiler, segmental spaces require to be measured, and for this purpose the foregoing tabular area of 500 segments or one-half of a circle whose diameter is 1, or unity, will be useful. The areas are in square measure, which requires to be multiplied by 1·273 for circular inches.

The following practical examples will show how part of these exponents may be usefully applied to ascertain very nearly the quantity of water which is in any boiler or tender, or other vessel.

EXAMPLE 1.—Taking the dimensions of the *Lord of the Isles*' locomotive boiler to be as under, required the quantity of water in tons and in gallons which would fill it to the water line 9 inches below the top of the cylindrical part of the boiler.

Dimensions.

CYLINDRICAL PART, 11 ft. long by 58 in. diameter, containing 303 tubes each 2 in. external diameter, and 10 iron stay rods each 1¼ in. diameter. Steam space a segment of the top of this part whose height or versed sine is 9 in.

Fire-box part, 71 in. wide, 66 in. long, and 63 in. mean depth.
Less inside fire-box, 64 „ 60 „ 63 „

Leaving water spaces—
Front and back, 71 in. wide, 63 in. deep, and 3 in. mean space.
Two sides, each 60 in. long, 63 „ 3½ „
Top of fire-box, 69 in. wide, 9 „ 66 in. long.
Partition, 63 „ 51 „ 4 in. space.
Less—
Circ. in.
Fire-door, 21″ × 18″ × 3″ tubes, =1,212 × 3 in. long.
12 stays 1½ × 6½ × 60, 10 stay-rods 1¼ diam. × 66 in. long.

Steam space, a segment of the top of the fire-box whose height or versed sine is 15 inches of a circle 71 inches diameter.

Boiler.

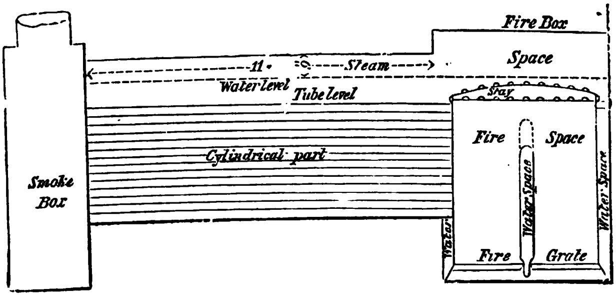
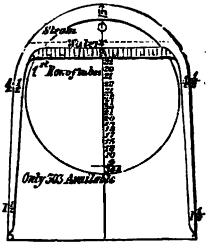


Fig. 74.—Longitudinal Section.



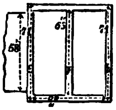


Fig. 75.—Transverse Section of Fire-Box. Fig. 76.—Plan of Fire-Box.

These three diagrams give an outline of the internal arrangement of the water, fire, and steam spaces in the *Lord of the Isles'* locomotive boiler.

Fig. 74 is a longitudinal section, showing the front and back water spaces between the outside shell of the boiler and inside fire-box. The transverse central water space which reaches up to the level of the fire door in the centre, and higher at the sides, is also shown. The fire-box is thus divided into two rectangular spaces, whose flat sides are strongly secured by numerous copper stays to the outside shell to resist the force of the steam. From the smallness of the diagrams these stays are not shown, but only one of the strong wrought-iron stays necessary to support the flat top of the fire-box; 303 tubes, each 11 ft. long by 2 inches external diameter, convey the heated gases from the fire to the chimney, usually placed on the top of the smoke-box. The line of the water level shows the comparative depth of the sectional steam and water spaces, whilst the line of the tubes and top of the fire-box shows the heating space.

Fig. 75 is a transverse sectional view of the fire-box, showing the two side water spaces between the inside and outside boxes, which are also strongly secured together by copper stays. The complete circle shows the area of the cylindrical part of the boiler, and the larger circle the area of the fire-box outside shell. The water line shows the comparative steam space in each of these parts.

Fig. 76 is a plan of the fire-box, showing how the circulation of the water spaces is arranged, and which spaces communicate with the cylindrical part below the tubes, as shown in Fig. 74.

From these dimensions we have for the cylindrical parts—

	Cir. in.	Cir. in.
Sectional area of boiler $= 58^2$		$= 3364$
Less tubular area of 303 tubes $\times 2^2 =$	1212	
And segmental steam space $= \frac{9}{58} = {\cdot}155 = {\cdot}07747$ (tab. num.) $\times 58^2 = 260$ sq. in. $\times 1{\cdot}273$ . . .	$= 331$	
		1543
Leaving a sectional water area of		1821

Which multiplied by the length $= 1821 \times 132 = 240{,}372$ cy. in.
The tubular space $= 1212$ area $\times$ 132 length $= 159{,}984$ cy. in.
The steam space $= 331$ area $\times$ 132 length $= 43{,}692$ cy. in.

For the fire-box or rectangular parts we have—

			Cub. in.
Front and back spaces	=71 in.×63 in. deep× 3 in. wide×2		=26838
Side spaces	=60 in.×63 in. deep× 3½ in. wide×2		=26460
Partition spaces	=63 in.×51 in. deep× 4 in. wide×1		=12852
Top of fire-box	=66 in.× 9 in. deep×69 in. wide×1		=40986
			107136
Deduct for back tubes	=1212 cub. in.× 3 ×·7854	=2856	
For front fire-door	=21 × 18 × 13	=1134	
For stays of sides, ends, and partitions, $\frac{1}{16}$ of space		=4134	
For top of box-stays $\frac{1}{5}$ of water space		=8193	
			16317
			90819

Or by taking the space included within the outside fire-box, and deducting the inside one, thus,

Outside box	=71 wide × 66 long × 63 deep	=295218
Less inside box	=64 wide × 60 long × 63 deep	=241920
		53298
Add partition and top as above . . .		53838
		107136
Less deductions as above		16317
Total water space round fire-box . .		90819

Steam space=$\frac{15}{71}$=·211=·120713 (tab. num.)×71^2=609 sq. in. area, and 609 × 66 length=40,014 sq. in. steam space on top of fire-box.

SUMMARY.

Steam Space.

	Cub. in.	Cy. in.	or	Cub. in.
Cylindrical part=		43692	× ·7854	=34315
Fire-box part	=40014 × 1·273	=50938	×	=40014
Total steam space . .		94630	or	74329

Compared with the capacity of the cylinders .

$$=18 \text{ in. diameter by } 24 \text{ in. stroke}=18^2\times 24=\frac{94630}{7776}=12{\cdot}17$$

times the capacity of 1 cylinder, or 6 times the capacity of the two cylinders.

Water Space.

	Cub. in.	Cy. in.	or	Cub. in.
Cylindrical part=		240372	× ·7854	=188788
Fire-box part	=90819 × 1·273	=115612		= 90819
Total water space . .		355984	or	279607

$$\begin{array}{llllllll} & \text{Cyl. in.} & \text{lbs.} & \text{lbs. av.} & & \text{t.} & \text{c.} & \text{q.} \ \ \text{lbs.} \\ \text{And } & 355984 \times & \cdot 02842 = & \dfrac{10117}{2240} & = 4\cdot516 \text{ tons, or} & 4 & 10 & 1 \ \ \ 7 \end{array}$$

$$\text{And } 355984 \times \cdot 00284 \qquad = 1011\cdot7 \text{ gallons of water.}$$

And by cubic measure,

$$\begin{array}{llllllll} \text{Cub. in.} & \text{lbs.} & \text{lbs. av.} & & \text{t.} & \text{c.} & \text{q.} \ \ \text{lbs.} \\ 279607 \times & \cdot 03617 = & \dfrac{10113}{2240} & = 4\cdot514, \text{ or} & 4 & 10 & 1 \ \ \ 3 \end{array}$$

$$\text{and } 279607 \times \cdot 00361 \qquad = 1011\cdot3 \text{ gallons.}$$

being a difference of 4 lbs. on the whole quantity, arising from the exponents being approximate and not strictly correct, but sufficiently near for practical purposes.

Heating Space.

	Cub. in.		Cy. in.		Cub. in.
Tubular space =			159984	× ·7854 =	125651
Fire-box	= 241920	× 1·273 =	307964		= 241920
Total heating space . .			467948	or	367571

Tabular Abstract of Boiler Contents.

	Cy. in.		Cub. in.		Cub. ft.
Steam space	94630	or	74329	or	43·02
Water space	355984	or	279607	or	161·80
Heating space	467948	or	367571	or	212·70

Example 2.—Taking the dimensions of the tender water-tank of the *Lord of the Isles'* locomotive engine as under, fig. 77, required the quantity of water it will contain in lbs., in tons, and in gallons?

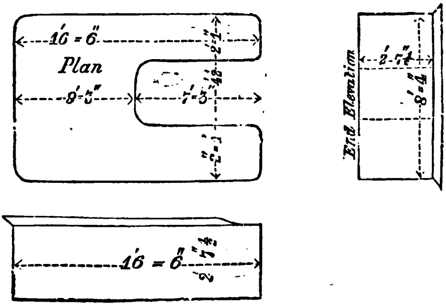


Fig. 77.—Tank of Tender.

Length, 16' 6"; width, 8' 4"; depth, 2' 7½"; less coke space, 7' 3" long and 4' 2" wide and 2' 7½" deep,

		Cub. in.	Cub. ft.
	178″×100″×31·5″	=523700÷1728	=360·9
less	87″× 50″×31·5″	=137025÷1728	= 79·3
		486675	281·6.

Cub. in. lbs.
and 486675×·03617=17603 lbs.
which divided by 2240=7 tons 17 cwt. 0 qr. 18 lbs.
for gallons 486675×·00361=1760 gallons,
or 281·6 cube ft.×6·25=1760 gallons.

Abstract of Tender Contents.

	Cub. in.		Cub. ft.
Coke space . . .	137025	or	79·27
Water space . .	623700	or	360·90.

IMPURITIES OF WATER.

Since nothing but pure water is converted into pure steam, the impurities of water are either deposited on the boiler or, by the action of chemical agents, partly carried away in the steam, to the detriment of slide-valves and pistons. The following Table will convey an idea of the impurities in well, river, and canal water.

All the London waters are from Professor Brande's Report. The New Swindon water is by Dr. Herapath, the eminent chemist, of Bristol.

TABLE No. IV.

IMPURITIES IN ONE GALLON OF WATER.

(70,000 grains = 1 imperial gallon.)

		Grains.		Per Cent.
Thames at	Greenwich . . .	27·9	Average, 23·2 or ·0033	·00398
„	London Bridge . .	28·		·004
„	Westminster . .	24·4		·0035
„	Brentford . . .	19·2		·00274
„	Twickenham . .	22·4		·0032
„	Teddington . .	17·4		·0025
New River		19·2		·002
Colne		21·3		·00304
Lea		23·7		·00338
Ravensborne, at Deptford . .		20·		·00285
Coombe and Delafield's Well, deep		56·8		·0081

TABLE No. IV. (*continued*).

		Grains.	Per Cent.
Apothecaries' Hall, Blackfriars,	deep	45·	·00643
Notting Hill	„	60·6	·00865
Royal Mint	„	37·8	·0054
Hampstead Water Works	„	40·	·00571
Berkeley Square	„	60·	·00857
Tilbury Fort	„	75·	·01071
Goding's Brewery	„	50·	·00714
„	shallow	110·	·01571
More's Brewery, Old Street,	deep	38·9	·005557
„	shallow	110·	·0157
Trafalgar Square Fountains,	deep	68·9	·00984
St. Paul's Churchyard	„	75·	·01071
Bream's Buildings		115·	·01643
St. Giles, Holborn		105·	·015
St. Martin's, Charing Cross		95·	·01357
Postern Row, Tower		98·	·014
Artesian Well at Grenelle, Paris		9·86	
New Swindon Canal, filtered		32·16	·00014

Of these a detailed analysis of the Royal Mint water, by Professor Brande, and of the New Swindon filtered canal water, by W. Herapath, Esq., of Bristol, will show the nature of these impurities.

In one gallon of water from the Royal Mint well there were—

Proximate Saline Components.

	Grains.
Chloride of sodium	10·53
Sulphate of soda	13·14
Carbonate of soda	8·63
„ lime	3·5
„ magnesia	1·5
Silica	0·5
Organic matter	traces of.
Phosphoric acid	
Iron	

Substances in the Water.

Sulphuric acid	7·44
Chlorine	6·31
Carbonic acid (after boiling)	5·84
Silica	0·50
Sodium combined with chlorine	4·22

	Grains.
Soda combined with sulphuric and carbonic acid	10·87
Lime	1·96
Magnesia	0·71
Organic matter	traces of.
Phosphoric acid	
Iron	

In one gallon of New Swindon water there were—

	Grains in a Gallon.
Chloride of magnesium (bittern)	·464
Sulphate of „ (Epsom salts)	·048
Sulphate of soda (glauber salts)	5·744
Chloride of sodium (common salt)	2·736
Carbonate of lime (chalk)	12·16
Sulphate of lime (gypsum)	10·4
Organic matter (vegetable extract)	·608
	32·16

This water averages 20 grains of hardness, as it is called, which is more than the average of the London or Bristol spring waters, which run from 12 to 16 grains. By boiling the water is reduced to 12 grains hardness.

These analyses of water indicate that locality has much to do with its comparative purity, and that in London the shallow wells above the chalk, or about 200 to 220 feet deep, are more impure than those deep wells which draw their supplies below the chalk, or about 400 to 426 feet deep, as at the Royal Mint.

By knowing the particular impurities in any particular water, the practical engineer can decide with confidence whether it is or is not desirable to employ any chemical agent, such as oxalic acid, carbonate of potash, or soda, to precipitate, or nitric, muriatic, or acetic acid, to hold in solution and pass through with the steam some one of these impurities.

If only one agent, such as muriate of ammonia, be used, which thus holds in solution one of the impurities, say carbonate of lime, whilst the others, such as the sulphate of lime, are deposited by boiling; then it may even be more than doubtful if there be any present gain, and scarcely doubtful as to future injury to the rubbing surfaces of the machinery and to the boiler itself.

The effect of acids on iron is well known, and, notwithstanding their dilution when used in boilers, they appear to exercise injurious effects on particular makes of iron. In some locomotive boilers where muriate of ammonia has been employed, the internal surface of the part below the tubes was so deeply oxydized in numerous spots as to render it necessary to replace the plates to prevent accidents. In other boilers this effect is not so apparent. This difference is probably owing to the quality of the iron, or to the greater or lesser quantity of oxygen or other bodies it contains, having more or less affinity for acids. Similar results are observed from the action of the fire upon copper fire-boxes, where one fire-box will last much longer than another. The advocates of these chemical agents deny their injurious action, but the accumulating evidence of observed destruction of tender tanks and boilers is a strong presumption that they cannot be used safely with every sort of iron, even if their employment were otherwise beneficial. Dr. Davies's analysis of deposits in locomotives shows that they contain carbonate and sulphate of lime with a little magnesia, protoxide of iron, silica and carbonaceous matter.

CHAPTER V.

HEAT.

HEAT is measured by an instrument called a *thermometer*, and the quantity, indicated on a scale of equal parts, is designated its *temperature*.

The general effect of heat upon all bodies is to increase their bulk in some unascertained ratio to their destiny and molecular formation, excepting those bodies which diminish in volume, by heat evaporating the water they contain, such as newly cut peat or clay.

Solids expand least, fluids next, and gases most by equal increments of heat. As compared with each other, neither solids nor fluids of the same class expand equally—a fact which has hitherto prevented any general law being defined for the rate of expansion of each class. Usually, though not always, the lighter bodies expand more than the heavier ones, as alcohol expands more than water, and water more than mercury.

Platinum, gold, silver, and zinc follow the general law; but copper, iron, and marble form exceptions.

The following Table (No. V.) shows, in average, the lineal expansion of solid bodies, from 32° to 212°.

The linear expansion multiplied by three gives the *total* or cubical expansion nearly. Thus for iron it would be 1 in 271, and for lead 1 in 117. The contracting power of expanded iron is usefully employed in various ways; it was the means used to draw the walls of the Museum of Arts in Paris from an inclining to a vertical position.

TABLE No. V.

AVERAGES OF THE LINEAR EXPANSION OF METALS FROM 32° TO 212°.

Name.	Increased length at 212°.	Name.	Increased length at 212°.
Zinc, sheet	1 part in . . 340	Iron	1 part in . . 812
Zinc, cast	,, . . 322	Antimony	,, . . 923
Lead	,, . . 351	Palladium	,, . . 1000
Tin, pure	,, . . 403	Platinum	,, . . 1167
Tin, impure	,, . . 516	Glass	,, . . 1160
Silver	,, . . 524	Marble	,, . . 2833
Copper	,, . . 581	Iron, soft	,, . . 818
Brass	,, . . 584	Iron, cast	,, . . 900
Gold	,, . . 682	Steel, tempered	,, . . 806
Bismuth	,, . . 719	Steel	,, . . 926

Sheet zinc, as employed on roofs of buildings or for covering locomotive boilers, exhibits in a marked manner the effects of expansion, in causing it to "blister and crack," which renders it an inferior article for such purposes.

The following Tables show the expansion of fluids and of air from 32° to 212° F.; not lineally, but by volume;—

TABLE No. VI.

EXPANSION OF FLUIDS BY THE ADDITION OF 180° OF HEAT, OR AT 212°.

Name.			Volume at 32°, Cub. ft.		at 212°. Cub. ft.
Air	1 part in	2·74 or	1000	become	1366
Alcohol	1	9	1000		1110
Nitric acid (s. g. 1·4)	1	9	1000		1110
Fixed oils	1	12	1000		1080
Turpentine	1	14	1000		1070
Sulphuric ether	1	14	1000		1070
Sulphuric acid (s. g. 1·85) . .	1	17	1000		1060
Hydrochloric acid (s. g. 1·137) .	1	17	1000		1060
Salt water	1	20	1000		1050
Water	1	22	1000		1047
Mercury	1	55	1000		1018
Mercury, apparent in glass .	1	65	1000		1015

The Table No. VII. shows the volumes of one pound of air at temperatures from 32° to 212° F., together with the ratios of these volumes; the volume at 62° being taken as 1·000. The pressure is assumed to be constant, and equal to the atmospheric pressure of 14·7 lbs. per square inch.

TABLE No. VII.

VOLUME OF ONE POUND OF AIR AT TEMPERATURES FROM 32° TO 212° F.

Temperature.	Volume of one pound of air, at a constant pressure of 14·7 lbs. per square inch.		Temperature.	Volume of one pound of air, at a constant pressure of 14·7 lbs. per square inch.	
Fahr.	Cubic feet.	Ratio.	Fahr.	Cubic feet.	Ratio.
32°	12·387	.943	120°	14·592	1·111
40	12·586	·958	140	15·100	1·149
50	12·840	·977	160	15·603	1·187
62	13·141	1·000	180	16·106	1·226
70	13·342	1·015	200	16·606	1·264
80	13·593	1·034	210	16·860	1·283
90	13·845	1·054	212	16·910	1·287
100	14·096	1·073			

Thermometers.

The general law of expansion by heat, as shown in these tables, suggested the mode of measuring the heat in any body by comparison with the rate of expansion in a given body. The medical advantages of determining the comparative temperatures of the body and the air in sick-chambers led Sanctori, an Italian physician, to construct an air thermometer in 1590, to aid him in his practice, being the earliest we have an account of. In 1655, alcohol was substituted for air; and although both air and spirit thermometers are employed in scientific investigations at very high or very low temperatures, mercurial thermometers are generally used.

The qualities of mercury for the thermometer are its fluidity through a range of 687° under atmospheric pressure, and about 630° in the vacuum of a thermometer, where its fluidity extends 39° below the freezing point of water, and 378° above its boiling point. Mercury is not, however, a perfect material, as its rate of expansion increases for equal increments of heat at high temperatures, and it also deteriorates by use, which renders it necessary to check its indications for minute investigations by the more uniform expansion of the air thermometer.

Its specific gravity is 13·6. At 590°, it begins to boil in the thermometer, but it does not boil until 687° in the open air.

Mercurial Thermometer.

This instrument is usually made with a slender glass tube of equal bore, having an enlarged end, which, with a part of the tube, is filled with mercury. It is then made to boil, that the expansion of the mercury may expel the air from the unfilled part of the tube, when the open end is fused together to prevent the admission of any more air. Thus enclosed from the pressure of the atmosphere, the mercury ascends by expansion as heat is communicated to it, or descends by contraction as heat is withdrawn from it. To give two fixed points in a scale of parts for the rise and fall of mercury, the freezing and boiling points of water are adopted.

These points are obtained by immersing the prepared tube containing mercury alternately in freezing and boiling water, and marking the level at which the mercury becomes stationary in each trial. The distance between these points is then divided into a number of equal parts, and the scale extended as required. In this country thermometers are understood to be so adjusted, when the pressure of the air supports 30 inches of mercury.

It is to be regretted that the thermometers of different countries are differently divided. The distance between the freezing and boiling points is by Fahrenheit divided into 180 parts, by De Lisle into 150 parts, by Celsius into 100 parts, hence called the Centigrade scale, and by Réaumur into 80 parts, whose thermometers are all in use in different parts of Europe. Diagrams figs. 78, 79, 80 and 81 will show the relation these scales bear to each other.

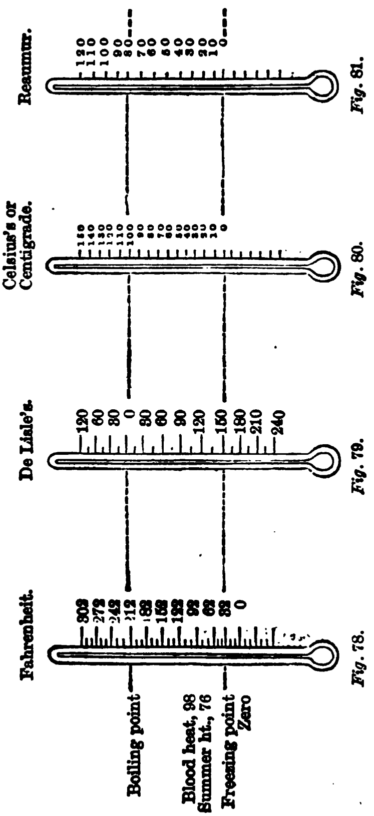


Fig. 78. *Fig.* 79. *Fig.* 80. *Fig.* 81.

Fig. 78. 1 = 5/9 of 1 of Cent.; or = 4/9 of 1 of Reaum.; or = 5/6 of 1 of De Lisle's.
Fig. 79. 1 = 1⅕ of 1 of Fah.; or = 10/15 of 1 of Cent.; or = 8/15 of 1 of Reaum.
Fig. 80. 1 = 1½ of 1 of De Lisle's; or = 4/5 of 1 of Reaum.; or = 1⅘ of 1 of Fah.
Fig. 81. 1 = 1¼ of 1 of Cent.; 1 = 2¼ of 1 of Fah.; 1 = 1⅞ of 1 of De Lisle's.

Comparatively, therefore, the preceding thermometers stand thus:

	Fahr.		De Lisle.		Celsius or Cent.		Reaum.
Boiling	212		0		100		80
Freezing	32		150		0		0
No. of equal parts =	180		150		100		80
Ratio of parts =	9	=	7·5	=	5	=	4

or thus :—

1° of Fahr. = 5/6 of 1 of De Lisle's, or Fahr. × 5/6 = De Lisle's.
1 „ = 5/9 of 1 of Cent. „ × 5/9 = Cent.
1 „ = 4/9 of 1 of Reaum. „ × 4/9 = Reaum.

1° of De Lisle's	$=1\frac{1}{5}$ of 1 of Fahr.,	or De Lisle's	$\times\frac{6}{5}=$ Fahr.
1 „	$=\frac{10}{15}$ of 1 of Cent.	„	$\times\frac{10}{15}=$ Cent.
1 „	$=\frac{8}{15}$ of 1 of Reaum.	„	$\times\frac{8}{15}=$ Reaum.
1° of Cent.	$=1\frac{4}{5}$ of 1 of Fahr.,	or Cent.	$\times\frac{9}{5}=$ Fahr.
1 „	$=1\frac{1}{2}$ of 1 of De Lisle's	„	$\times\frac{3}{2}=$ De Lisle's.
1 „	$=\frac{4}{5}$ of 1 of Reaum.	„	$\times\frac{4}{5}=$ Reaum.
1° of Reaum.	$=2\frac{1}{4}$ of 1 of Fahr.,	or Reaum.	$\times\frac{9}{4}=$ Fahr.
1 „	$=1\frac{7}{8}$ of 1 of De Lisle's	„	$\times\frac{15}{8}=$ De Lisle's.
1 „	$=1\frac{1}{4}$ of 1 of Cent.	„	$\times\frac{5}{4}=$ Cent.

The multipliers are thus used—

$$180 \text{ Fahr.} \times \frac{5}{6} = \frac{180 \times 5}{6} = 150° \text{ De Lisle's.}$$

$$150 \text{ De Lisle's} \times \frac{6}{5} \text{ or } 1{\cdot}2 = \frac{150 \times 6}{5} = 180° \text{ Fahr.}$$

$$\text{or } 150 \times 1{\cdot}2 = 180° \text{ Fahr.}$$

$$80 \text{ Reaum.} \times \frac{15}{8} = \frac{80 \times 15}{8} = 150° \text{ De Lisle's.}$$

$$180 \text{ Fahr.} \times \frac{5}{9} = \frac{180 \times 5}{9} = 100° \text{ Cent.}$$

$$100 \text{ Cent.} \times \frac{9}{5} \text{ or } 1{\cdot}8 = \frac{100 \times 9}{5} = 180° \text{ Fahr.}$$

$$\text{or } 100 \times 1{\cdot}8 = 180° \text{ Fahr.}$$

Whilst by these multipliers we are enabled to convert the degrees of one into those of the other, yet, as their notation is different, it requires attention to subtract the 32° of Fahrenheit from the reading off other scales, before the multiplier is used. Thus Fahr. $212° - 32 \times \frac{5}{9} = 100°$ Cent.

From the freezing point to zero, it requires the number for a Fahrenheit scale to be subtracted from 32°. Thus,

$$\text{Fahr. } 14, \text{ then } 32 - 14 \times \tfrac{5}{9} = 10 \text{ Cent.}$$

Below zero, it requires the 32° to be added. Thus,

$$\text{Fahr.} -58° + 32° \times \tfrac{5}{9} = 50° \text{ Cent.,}$$

and in like manner with Réaumur's scale.

De Lisle's notation, commencing at 212° Fahrenheit's, 100° Cent., and 80° Réaumur, requires the quantity found by the multipliers to be deducted from 150° for the reading on his scale: thus 206° Fah. = 5° De Lisle's, for

$\frac{206-32\times5}{6}$ 145 and 150−145=5° De Lisle's.

For it will be observed they differ in their zero or starting-point as well as in their scale of parts. Fahrenheit having, in 1709, artificially obtained a degree of cold 32° below the freezing point of water, imagined it to be the greatest possible cold, and fixed it as the starting-point for his scale used in this country. Recent experiments have, however, reached as low as 166° below Fahrenheit's zero. Réaumur, in 1730, fixed his zero at the freezing point, as also did Celsius, whose scale is used in France; but, in 1733, De Lisle fixed his zero at the boiling point. Thus, in reading off De Lisle's own scale, say at 80°, it would be 150° (the range between boiling and freezing) — 80 = 70° above the freezing point.

From this brief explanation of thermometers it will be obvious that one uniform scale, such as the centigrade or decimal scale, would be far preferable for both scientific and practical purposes, avoiding a constant recourse to calculation to ascertain the comparative temperatures.

In this respect the following Table will be found useful.

TABLE No. VIII.

COMPARATIVE TEMPERATURES BY FAHR., DE LISLE, CENTIGRADE, REAUM., FROM 600° FAHR. TO FREEZING POINT OF MERCURY.

Fahr.	De Lisle.	Cent.	Reaum.	Fahr.	De Lisle.	Cent.	Reaum.
600	323·3	315·5	252·4	430	181·6	221·1	176·8
580	306·6	304·4	243·5	420	173·3	215·5	172·4
560	290·6	293·3	234·6	410	165·	210·	168·
540	273·3	282·2	225·7	400	156·6	204·4	163·5
520	256·6	271·1	216·8	395	152·4	201·6	161·3
500	240·	260·	208·	390	148·3	198·8	159·1
490	231·6	254·4	203·5	385	144·1	196·1	156·9
480	223·3	248·8	199·1	380	140·	193·2	154·6
470	215·	243·3	194·6	375	135·8	190·5	152·4
460	206·6	237·7	199·2	370	131·6	187·7	150·2
450	198·3	232·2	185·8	365	127·5	185·	148·
440	190·	226·6	181·4	360	123·3	182·2	145·8

Fahr.	De Lisle.	Cent.	Reaum.	Fahr.	De Lisle.	Cent.	Reaum.
355	119·16	179·4	143·5	302	75·	150·	120·
350	115·	176·6	141·3	301	74·1	149·4	119·5
345	110·83	174·	139·	300	73·3	148·8	119·1
340	106·6	171·1	136·8	299	72·5	148·3	118·6
339	105·8	170·5	136·4	298	71·6	147·7	118·2
338	105·	170·	136·	297	70·8	147·2	117·7
337	104·1	169·4	135·5	296	70·	146·6	117·3
336	103·3	168·8	134·1	295	69·1	146·1	116·8
335	102·5	168·3	134·6	294	68·3	145·5	116·4
334	101·6	167·7	134·2	293	67·5	145·	116·
333	100·8	167·2	133·7	292	66·6	144·4	115·5
332	100·	166·6	133·3	291	65·8	143·8	115·1
331	99·1	166·1	132·8	290	65·	143·3	114·6
330	98·3	165·5	132·4	289	64·1	142·7	114·2
329	97·5	165·	132·	288	63·3	142·2	113·7
328	96·6	164·4	131·5	287	62·5	141·6	113·3
327	95·8	163·8	131·1	286	61·6	141·6	112·8
326	95·	163·3	130 6	285	60·8	140·5	112·4
325	94·1	162·7	130·2	284	60·	140·	112·
324	93·3	162·2	129·7	283	59·1	140·4	111·5
323	92·5	161·6	129·3	282	58·3	139·8	111·1
322	91·6	161·1	128·8	281	57·5	139·3	110·6
321	90·8	160·5	128·4	280	56·6	138·7	110·2
320	90·	160·	128·	279	55·8	138·2	109·7
319	89·1	159·4	127·5	278	55·	137·6	109·3
318	88·3	158·8	127·1	277	54·1	136·1	108·8
317	87·5	158·3	126·6	276	53·3	135·5	108·4
316	86·6	157·7	126·2	275	52·5	135·	108·
315	85·8	157·2	125·7	274	51·6	134·4	107·5
314	85·	156·6	125·7	273	50·8	133·8	107·1
313	84·1	156·1	124·8	272	50·	133·3	106·6
312	83·3	155·5	124·4	271	49·1	132·7	106·2
311	82·5	155·	124·	270	48·3	132·2	105·7
310	81·6	154·4	123·5	269	47·5	131·6	105·3
309	80·8	153·8	123·1	268	46·6	131·1	104·8
308	80·	153·3	122·6	267	45·8	130·5	104·4
307	79·1	152·7	122·2	266	45·	130·	104·
306	78·3	152·2	121·7	265	44·1	129·4	103·5
305	77·5	151·6	121·3	264	43·3	128·8	103·1
304	76·6	151·1	120·8	263	42·5	128·3	102·6
303	75·8	150·5	120·4	262	41·6	127·7	102·2

Fahr.	De Lisle.	Cent.	Reaum.	Fahr.	De Lisle.	Cent.	Reaum.
261	40·8	127·2	101·7	220	6·6	104·4	83·5
260	40·	126·6	101·3	219	5·8	103·8	83·1
259	39·1	126·1	100·8	218	5·	103·3	82·6
258	38·3	125·5	100·4	217	4·1	102·7	82·2
257	37·5	125·	100·	216	3·3	102·2	81·7
256	36·6	124·4	99·5	215	2·5	101·6	81·3
255	35·8	123·8	99·1	214	1·6	101·1	80·8
254	35·	123·3	98·6	213	·8	100·5	80·4
253	34·1	122·7	98·2	212	zero	100·	80·
252	33·3	122·2	97·7	211	·8	99·4	79·5
251	32·5	121·6	97·3	210	1·6	98·8	79·1
250	31·6	121·1	96·8	209	2·5	98·3	78·6
249	30·8	120·5	96·4	208	3·3	97·7	78·2
248	30·	120·	96·	207	4·1	97·2	77·7
247	29·1	119·4	95·5	206	5·	96·6	77·3
246	28·3	118·8	95·1	205	5·8	96·1	76·8
245	27·5	118·3	94·6	204	6·6	96·5	76·4
244	26·6	117·7	94·2	203	7·5	95·	76·
243	25·8	117·2	93·7	202	8·3	94·4	75·5
242	25·	116·6	93·3	201	9·1	93·8	75·1
241	24·1	116·1	92·8	200	10·	93·3	74·6
240	23·3	115·5	92·4	199	10·8	92·7	74·2
239	22·5	115·	92·	198	11·6	92·2	73·7
238	21·6	114·4	91·5	197	12·5	91·6	73·3
237	20·8	113·8	91·1	196	13·3	91·	72·8
236	20·	113·3	90·6	195	14·1	90·5	72·4
235	19·1	112·7	90·2	194	15·	90·	72·
234	18·3	112·2	89·7	193	15·8	89·4	71·5
233	17·4	111·6	89·3	192	16·6	88·8	71·1
232	16·6	111·1	88·8	191	17·5	88·3	70·6
231	15·8	110·5	88·4	190	18·3	87·7	70·2
230	15·	110·	88·	189	19·1	87·2	69·7
229	14·1	109·4	87·5	188	20·	86·6	69·3
228	13·3	108·8	87·1	187	20·8	86·1	68·8
227	12·5	108·3	86·6	186	21·6	85·5	68·4
226	11·6	107·7	86·2	185	22·5	85·	68·
225	10·8	107·2	85·7	184	23·3	84·4	67·5
224	10·	106·6	85·3	183	24·1	83·8	67·1
223	9·1	106·1	84·8	182	25·	83·3	66·6
222	8·3	105·5	84·4	181	25·8	82·7	66·2
221	7·5	105·	84·	180	26·6	82·2	65·7

Fahr.	De Lisle.	Cent.	Reaum.	Fahr.	De Lisle.	Cent.	Reaum.
179	27·5	81·6	65·3	138	61·6	58·8	47·1
178	28·3	81·1	64·8	137	62·5	58·3	46·6
177	29·1	80·5	64·4	136	63·3	57·7	46·2
176	30·	80·	64·	135	64·1	57·2	45·7
175	30·8	79·4	63·5	134	65·	56·6	45·3
174	31·6	78·8	63·1	133	65·8	56·1	44·9
173	32·5	78·3	62·6	132	66·6	55·5	44·4
172	33·3	77·7	62·2	131	67·5	55·	44·
171	34·1	77·2	61·7	130	68·3	54·4	43·5
170	35·	76·6	61·3	129	69·1	53·8	43·1
169	35·8	76·1	60·8	128	70·	53·3	42·6
168	36·6	75·5	60·4	127	70·8	52·7	42·2
167	37·5	75·	60·	126	71·6	52·2	41·7
166	38·3	74·4	59·5	125	72·5	51·6	41·3
165	39·1	73·8	59·1	124	73·3	51·1	40·8
164	40·	73·3	58·6	123	74·1	50·5	40·4
163	40·8	72·7	58·2	122	75·	50·	40·
162	41·6	72·2	57·7	121	75·8	49·4	39·5
161	42·5	71·6	57·3	120	76·6	48·8	39·1
160	43·3	71·1	56·8	119	77·5	48·3	38·6
159	44·1	70·5	56 4	118	78·3	47·7	38·2
158	45·	70·	56·	117	79·1	47·2	37·7
157	45·8	69·4	55·5	116	80·	46·6	37·3
156	46·6	68·8	55·1	115	80·8	46·1	36·8
155	47·5	68·3	54·6	114	81·6	45·5	36·4
154	48·3	67·7	54·2	113	82·5	45·	36·
153	49·1	67·2	53·7	112	83·3	44·4	35·5
152	50·	66·6	53·3	111	84·1	43·8	35·1
151	50·8	66·1	52·8	110	85·	43·3	34·6
150	51·6	65·5	52·4	109	85·8	42·7	34·2
149	52·5	65·	52·	108	86·6	42·2	33·7
148	53·3	64·4	51·5	107	87·5	41·6	33·3
147	54·1	63·8	51·1	106	88·3	41·1	32·8
146	55·	63·3	50·6	105	89·1	40·5	32·4
145	55·8	62·7	50·2	104	90·	40·	32·
144	56·6	62·2	49·7	103	90·8	39·4	31·5
143	57·5	61·6	49·3	102	91·6	38·8	31·1
142	58·3	61·1	48·8	101	92·5	38·3	30·6
141	59·1	60·5	48·4	100	93·3	37·7	30·2
140	60·	60·	48·	99	94·1	37·2	29·7
139	60·8	59·4	47·5	98	95·	36·6	29·3

Fahr.	De Lisle.	Cent.	Reaum.	Fahr.	DeLisle.	Cent.	Reaum.
97	95·8	36·1	28·8	56	130·	13·3	10·6
96	96·6	35·5	28·4	55	130·8	12·7	10·2
95	97·5	35·	28·	54	131·6	12·2	9·7
94	98·3	34·	27·5	53	132·5	11·6	9·3
93	99·1	33·4	27·1	52	133·3	11·1	8·8
92	100·	33·8	26·6	51	134·1	10·5	8·4
91	100·8	32·7	26·2	50	135·	10·	8·
90	101·6	32·2	25·7	49	135·8	9·4	7·5
89	102·5	31·6	25·3	48	136·6	8·8	7·1
88	103·3	31·1	24·8	47	137·5	8·3	6·6
87	104·1	30·5	24·4	46	138·3	7·7	6·2
86	105·	30·	24·	45	139·1	7·2	5·7
85	105·8	29·4	23·5	44	140·	6·6	5·3
84	106·6	28·8	23·1	43	140·8	6·1	4·8
83	107·5	28·3	22·6	42	141·6	5·5	4·4
82	108·3	27·7	22·2	41	142·5	5·	4·
81	109·1	27·2	21·7	40	143·3	4·4	3·5
80	110·	26·6	21·3	39	144·1	3·8	3·1
79	110·8	26·1	20·8	38	145·	3·3	2·6
78	111·6	25·5	20·4	37	145·8	2·7	2·2
77	112·5	25·	20·	36	146·6	2·2	1·7
76	113·3	24·4	19·5	35	147·5	1·6	1·3
75	114·1	23·8	19·1	34	148·3	1·1	0·8
74	115·	23·3	18·6	33	149·1	0·5	0·4
73	115·8	22·7	18·2	32	150·	zero	zero
72	116·6	22·2	17·7	31	150·8	0·5	0·4
71	117·5	21·6	17·3	30	151·6	1·1	0·8
70	118·3	21·1	16·8	29	152·5	1·6	1·3
69	119·1	20·5	16·4	28	153·3	2·2	1·7
68	120·	20·	16·	27	154·1	2·7	2·2
67	120·8	19·4	15·5	26	155·	3·3	2·6
66	121·6	18·8	15·1	25	155·8	3·8	3·1
65	122·5	18·3	14·6	24	156·6	4·4	3·4
64	123·3	17·7	14·2	23	157·5	5·	4·
63	124·1	17·2	13·7	22	158·3	5·5	4·4
62	125·	16·6	13·3	21	159·1	6·1	4·8
61	125·5	16·1	12·8	20	160·	6·6	5·3
60	126·6	15·5	12·4	19	160·8	7·2	5·7
59	127·5	15·	12·	18	161·6	7·7	6·2
58	128·3	14·4	11·5	17	162·5	8·3	6·6
57	129·1	13·8	11·1	16	163·3	8·8	7·1

Fahr.	De Lisle.	Cent.	Reaum.	Fahr.	De Lisle.	Cent.	Reaum.
15	164·1	9·4	7·5	14	188·3	25·5	20·4
14	165·	10·	8·	15	189·1	26·1	20·8
13	165·8	10·5	8·4	16	190·	26·6	21·3
12	166·6	11·1	8·8	17	190·8	27·2	21·7
11	167·5	11·6	9·3	18	191·6	27·7	22·2
10	168·3	12·2	9·7	19	192·5	28·3	22·6
9	169·1	12·7	10·2	20	193·3	28·8	23·1
8	170·	13·3	10·6	21	194·1	29·4	23·5
7	170·8	13·8	11·1	22	195·	30·	24·
6	171·6	14·4	11·5	23	195·8	30·5	24·4
5	172·5	15·	12·	24	196·6	31·1	24·8
4	173·3	15·5	12·4	25	197·5	31·6	25·3
3	174·1	16·1	12·8	26	198·3	32·2	25·7
2	175·	16·6	13·3	27	199·1	32·7	26·2
1	175·8	17·2	13·7	28	200·	33·3	26·6
zero	176·6	17·7	14·2	29	200·8	33·8	27·1
1	177·5	18·3	14·6	30	201·6	34·4	27·5
2	178·3	18·8	15·1	31	202·5	35·	28·
3	179·1	19·4	15·5	32	203·3	35·5	28·4
4	180·	20·	16·	33	204·1	36·1	28·8
5	180·8	20·5	16·4	34	205·	36·6	29·5
6	181·6	21·1	16·8	35	205·8	37·2	29·7
7	182·5	21·6	17·3	36	206·6	37·7	30·2
8	183·3	22·2	17·7	37	207·5	38·3	30·6
9	184·1	22·7	18·2	38	208·3	38·8	31·1
10	185·	23·3	18·6	39	209·1	39·4	31·5
11	185·8	23·8	19·1	40	210·	40·	32·
12	186·6	24·4	19·5	41	210·9	40·5	32·4
13	187·5	25·	20·	42	211·6	41·1	32·9

Note.—Temperatures below *zero*, for the several scales, are taken as negative.

Communication of Heat.

Heat is communicated from one body to another in three ways,

1st. By direct contact, called *Conduction.*
2nd. By right lines, called *Radiation.*
3rd. By carrying, called *Convection.*

Conduction.

When two bodies of unequal temperature are placed in contact with each other, the hotter body communicates heat to the colder body until they become of equal temperature. The rapidity of this equalisation depends upon the nature of the bodies themselves, as all bodies do not conduct heat alike, and are accordingly called good or bad conductors. Wood, for instance, is so bad a conductor of heat, that if a piece of it be set on fire at one end it can be held until the flame has reached the hand without the heat having been previously conducted by the fibres of the wood itself. Glass is also a bad conductor of heat. Fluids also conduct heat very slowly, mercury excepted. Metals are good conductors, but vary in their power of doing so, as seen in the following tabular classification of their comparative powers of conduction.

Gold	1000·	Tin	303·9
Platina	381·	Lead	179·6
Silver	973·	Marble	23·6
Copper	898·2	Porcelain	12·2
Iron	374·3	Fire-clay	11·4
Zinc	363·	Water	9·

The conducting power of metals may be experienced by holding the point of a pin in the flame of a candle, when the heat is rapidly conducted to the head until it cannot be held by the uncovered fingers.

Atmospheric air and gases have been generally regarded as bad conductors of heat; but recent investigators consider that the atmosphere conducts heat as rapidly as it does sound, but that their effects are rendered almost invisible from the small quantity of ponderable matter in the air.

Radiation.

When a hot body, such as a fire or a mass of metal, is surrounded by other bodies not in immediate contact, but placed at some distance from it, the heat from the hot body radiates from the centre in lines to the colder bodies, with a power inversely as the square of the distance from the centre. The greatest effect is upwards; the least effect is horizontally to the surface. The surface of the bodies receiving heat exercises a marked effect on the quantity absorbed in a given time. It was shown by Leslie that a tin vessel filled with hot water and covered over with lampblack possessed a radiating power = 100, but

Covered with	sealing wax	95
,, ,,	writing paper	98
,, ,,	resin	96
,, ,,	crown glass	91
,, ,,	china ink	88
,, ,,	red lead	80
,, ,,	plumbago or black lead	75
,, ,,	isinglass	75
,, ,,	tarnished lead	45
,, ,,	scratched tin	22
,, ,,	bright lead	19
,, ,,	mercury	20
,, ,,	polished iron	15
,, ,,	sheet tin	12

Here lampblack and white paper have nearly the same power, whilst China ink and black lead have much less. A thermometer is more affected by an equal amount of heat when coated with chalk than when coated with Indian ink, and a thermometer made with coloured spirits rises more, for equal heat, than an uncoloured one.

Painted bodies radiate much more than the same bodies not painted. Hammered metallic bodies radiate more slowly than when less dense: hammered silver has only a radiating power of 10; unhammered silver 13·7. When the surface of each is scratched the radiating power is inversely affected, for the radiating power of hammered is 18, and of the cast only 11·3. This leads to the inference that radiation depends upon a thin film at the surface regulated by the density, for the increase of radiating power of rough burnished silver is

$\frac{4}{5}$ of that of polished hammered, while the power of the cast rough in $\frac{1}{5}$th less than that of polished cast silver.

It has been considered that, at the same temperature, the radiating and absorbing power of bodies are equal. Much of the comparative economy of steam boilers depends upon their absorbing power; for no matter how ably the furnace performs its duty, if the heat given off from the fuel cannot be taken up as rapidly as it is produced, then of course waste exists. The rapidity of production of heat in a locomotive furnace is not favourable for the entire absorption of that heat: hence the advantage of the numerous thin metal tubes to divide and absorb the heat generated in the furnace. It is not the least merit in this class of boilers, that as the velocity increases so does the area of conduction or direct contact of the heat, whilst the area of radiation decreases in the same ratio. For as the draught upon the fire increases so does the length of the flame; consequently not only the fire box, but also a greater or lesser portion of the thin tubes in immediate contact with that flame, absorb heat by conduction, and the remainder of the tubular surface absorbs it by radiation from the passing gases.

Convection.

Convection or carrying is the power possessed by fluids of conveying heat acquired at one place to another place.

In boilers the heat is thus transmitted amongst the water. In the furnace the air carries the unabsorbed heat to the chimney. When the power of convection is much greater than the power of absorption, then the heat evolved during combustion is carried off without producing its proper effect. The greater therefore the absorbing power of any boiler, the greater will be its economy. In locomotive boilers at high velocities, this power of convection increases as the radiating surface decreases, and the loss of heat by convection is in proportion to the velocity of the escaping gases and the shorter distance passed over by them.

In solid bodies heat travels from atom to atom; but in fluid bodies the heated parts fly off and colder ones take their place until the heat has been diffused. It is only by convection that air transports heat, for if its circulation be stopped it nearly ceases to carry heat. Glass carries heat slowly, and it is estimated that a square foot of glass exposed on one side to the atmosphere will cool 1·279 cubic feet of air 1° per minute, when it is in contact with the glass.

Reflecting Power.

The reflecting power of different bodies is generally estimated as being inversely as the radiating power, so that if brass reflects 100 parts of heat, silver would reflect 90, and with these others as they stand below.

Brass	100
Silver	90
Tinfoil	85
Block tin	80
Steel	70
Lead	60
Tinfoil, softened by mercury	10
Glass	10
Glass, coated with wax	5

Specific Heat.

The specific heat, or the comparative capacity of bodies to receive heat, varies widely. Thus, if 1 lb. of mercury at 32° be mixed with 1 lb. of water at 62°, the temperature will become 61°, or if the mercury had been 62° and the water 32°, the common temperature would have been 33°, showing that the capacity of mercury for heat is about $\frac{1}{30}$ of that of water. Water is usually made the standard of comparison for ponderous bodies, and air for gaseous bodies. The specific heat of a solid or a liquid is expressed by the ratio of the capacity for heat of water, taken as 1, to that of the given body; and that of gases is similarly expressed, compared with air. The capacity of bodies for heat may be tested by the quantity of ice they will melt: thus, equal weights of iron and lead, heated to 100°, would melt, 11 grains by the iron, and only 3 grains by the lead, each falling to 95°.

The following is a table of specific heats. Those given for gases are for equal weights at constant pressure:—

TABLE No. IX.

Specific Heat of Different Bodies.

	Regnault.	Dulong.		
Iron	·1137	·110	Hydrogen	3·4046
Copper	·0951	·0949	Water	1·
Zinc	·0955	·0927	Steam (gaseous)	·475
Nickel	·1086	·1035	„ (saturated)	·305
Cobalt	·1069	·1498	Alcohol	·600 to ·700
Platinum	·0324	·0314	Ether	·6600
Gold	·0324	·0298	Oil	·520
Sulphur	·2026	·1880	Air	·2377
Carbon	·2411	·25	Nitrogen	·2440
Phosphorus	·1887	·385	Oxygen	·2182
Iodine	·05412	·089	Carbonic acid	·2164
Arsenic	·0814	·081	„ oxide	·2479
Lead	·0314	·0293	Charcoal	·2631
Bismuth	·0308	·0288	Oil of turpentine	·4160
Antimony	·0507	·0507	Sulphuric acid	·333
Indian Tin	·05623	·0514	Nitric acid	·426
Mercury	·0333	·0330	Iron at 212°	·110
Steel	·118		„ 392°	·115
Brass	·094		„ 372°	·122
Glass	·177		„ 662°	·126
Salt	·225		„ carbonate of	·1819
Marble	·205		Zinc „	·0955

The difference in the quantity of specific heat by different experimenters arises from the delicate nature of the experiments and the manner of performing them, in which the minutest error becomes magnified when generalized.

The capacity for heat increases with the temperature, as seen in iron, and in cooling a greater amount of heat is given out in cooling down an equal number of degrees at a high than at a low temperature.

To raise 1 lb. of water from 32° to 212° or 180° requires as much heat as would raise 4·27 lbs. of air through the same range; and the specific heats of air and water are as ·2377 is to 1.

Specific Heat by Volume.

Specific heat is, unless otherwise stated, reckoned by equal weights of the compared bodies, but it may also be reckoned by equal volumes. Thus the specific heat of gaseous steam is ·475, but its specific heat by volume at constant pressure is only $\frac{1}{14}$ of that of an equal volume of water.

The Mechanical Theory of Heat.

An important and interesting inquiry relative to steam and its operation in the steam-engine is that which traces the connection between the quantity ot heat expended and the dynamical effect, or work produced. The inquiries of scientific men into the subject of the relation of heat to mechanical effect, have resulted in the establishment of the principle that heat and mechanical force are identical and convertible, and that the action of a given quantity of heat may be represented by a constant quantity of mechanical work performed. For the exact expression of this relation, of course, units of measure are established,—in terms of the English foot as the measure of space; the pound avoirdupois as the measure of weight, pressure, elasticity; and the degree of Fahrenheit's scale as the measure of temperature and heat. The English unit of heat is that which is required to raise the temperature of 1 lb. of water 1 degree Fahr., and whether 2 lbs. of water be raised 1 degree, or 1 lb. of water be raised 2 degrees in temperature, the expenditure of heat is the same in amount, namely, 2 units of heat. The English unit of work, which consists of the sustained exertion of pressure through space, is one foot-pound; that is, a pressure of 1 lb. exerted through a space of one foot. The unit of heat, then, is capable of raising 772 lbs. weight one foot high, and its mechanical equivalent is expressible by 772 foot-pounds. This quantity is known as "Joule's equivalent," named after the investigator.

The following are the values of Joule's equivalent for different thermometric scales, and in English and French units:—

1 English thermal unit, or one degree Fahrenheit in one pound of water	772 foot-pounds.
1 French thermal unit, or one degree Centigrade, in one kilogramme of water . . .	423·55 kilogrammètres.
1 degree Centigrade in one pound of water .	1389·60 foot-pounds.

1 French thermal unit is equal to 3·97 English thermal units; say, 4 English units.

According to the mechanical theory of heat, all gases and vapours are assumed to consist of numerous small atoms, moving or vibrating in all directions with great rapidity, pressure being, as explained by Mr. Joule, the impact of those numerous small atoms striking in all directions, and against the sides of the vessel containing the gas. The greater the number of these atoms, or the greater their aggregate weight, in a given space, and the higher the velocity of impact, the greater is the pressure; and an increase or decrease of temperature is simply an increase or decrease of molecular motion. When the piston in the cylinder yields to the pressure of steam, the atoms will not rebound from it with the same velocity with which they strike, but will return after each succeeding blow, with a velocity continually decreasing as the piston continues to recede; and correspondingly the temperature is diminished.

In expanding a given volume of air spontaneously to double the volume, delivering it, say, into a vacuous space, it has been proved that the temperature of the air is not reduced, no external work being performed; but that, on the contrary, if the air at a temperature say of 230° Fahrenheit be expanded against an opposing pressure or resistance,—the piston of a cylinder, for example,—giving motion to it and raising a weight, or otherwise doing work, then the temperature will fall nearly 170° when the volume is doubled, that is, from 230° to about 60°; and supposing that the initial pressure be 40 lbs., the final pressure after the volume is doubled would be 15 lbs. per square inch.

If a body of compressed air be allowed to rush freely into the atmosphere, the temperature falls in the rapid part of the current by the conversion of heat into motion, but the heat is almost all reproduced when the motion has quite subsided. From recent experiments it appears that nearly similar results are obtained from the emission of steam under pressure.

If a body of water descends freely through a height of 772 feet, it acquires from gravity a velocity of 223 feet per second, and if suddenly brought to rest when moving with this velocity, it would be violently agitated, and would be raised one degree of temperature. But suppose a water-wheel 772 feet in diameter, into the buckets of which the water is quietly dropped; when the water descends to the foot of the fall, and is delivered gently into the tail-race, it is not sensibly heated.

From the preceding statements and illustrations of the nature and reciprocal action of heat and motive powers, it is apparent that the nature and extent of the change of temperature of a gas while expanding, depends nearly altogether upon the circumstances under which the change of volume takes place.

Combustion, or the Production of Heat.

Coal thrown on a fire evolves, amongst others, the two principal combustibles, carbon and hydrogen, which uniting with the oxygen of the air—an incombustible yet a necessary supporter of a fire—produces heat and light at the same time. Simple as this process may appear, its analysis is yet a complicated chemical problem. The chief agents operating in the furnace are carbon, hydrogen, and oxygen, and their union in certain proportions produces other bodies, as water or steam, carbonic oxide, carbonic acid, besides others of less practical importance.

Combustibles and Incombustibles.

A combustible body is one which actually burns, such as carbon. An incombustible body is one that does not itself burn. A supporter of combustion is one that does not burn, but gives strength and support to one that does burn, such as oxygen, which supports carbon in producing heat. A common fire exhibits the union of the carbon of the fuel and the oxygen of the air. A gas-light exhibits the union of carbon, hydrogen, and oxygen to produce both heat and light. In neither process is the oxygen burnt, but only the combustibles, carbon and hydrogen. In all ordinary circumstances, oxygen is an indispensable element of combustion, and its proper supply is a question of the first importance for economy of fuel. For instance, if only 8 parts of oxygen are admitted for each 6 parts of carbon evolved from the fuel, the combustion is very imperfect, and much of the heat of the fuel passes off in combustible gases, of which carbonic oxide is the chief. If, however, 16 parts of oxygen are admitted to combine with 6 parts of carbon, the combustion, if chemically completed, is 70 per cent. better than the last, producing steam and carbonic acid as the products of perfect combustion.

The following are the usually received definitions of chemical combination, mechanical mixture and the elements of combustion :—

Chemical Combinations.

When two bodies unite to form a third body distinct from either of the combining bodies, this is called chemical union, as when carbon and oxygen unite to form heat, carbonic oxide or carbonic acid, or with hydrogen to form water.

Mechanical Mixtures.

A mechanical mixture is one where the bodies have been brought together, but each retains its original qualities, such as sand and water, or the oxygen and nitrogen of the air, or heat and water in steam, all of which can be readily separated and restored to their original state again.

Atmospheric Air.

This important body which surrounds us, and supplies the oxygen, or *life* of our breath, besides its other invaluable features, is a mechanical mixture of rather more than one-fifth part of oxygen and rather less than four-fifth parts of nitrogen, sometimes called azote. The latter dilutes the former, and renders it adapted to the constitution of man and the animal creation; and but for this dilution of the oxygen by the nitrogen, constituted as we are, life would be an accelerated but short course, similar to the brilliance exhibited by a wax taper when plunged into a jar of oxygen on the lecture table. Oxygen is therefore the principal supporter of both life and combustion; but the peculiar uses of nitrogen are only clearly understood as indispensable to vegetation. An ordinary iron furnace is estimated to require 310 tons of air in 24 hours, or as much as 20,000 men. That it is the oxygen which is consumed in supporting ordinary combustion may be shown by covering an ordinary candle with a bell glass whose lower edge rests in water, to prevent a further supply of air inside the glass. As the enclosed oxygen is consumed the flame grows less and less until it is extinguished, and the contents are found to be nitrogen apparently unaltered, hydrogen, and carbonic acid. One cubic foot at 32° weighs 1·29 ounce.

Oxygen.

This gas was discovered by Dr. Priestley in 1774, and is considered to be one of the most abundant bodies in nature. It is a permanent colourless transparent gas without smell, and 1·106 times heavier than air, and one cubic foot at 32° weighs 1·428 ounces. It combines with many other bodies in a variety of ways, forming very distinctive compounds. For ordinary combustion and breathing it is supplied from the atmosphere; but for the lecture-room it can be readily obtained in several ways, one of which is by heating the chlorate of potash, and collecting the gas given off in a bladder or jar. If a taper with a single spark of fire left on its wick be placed in any jar of oxygen, it immediately burns forth with splendour, and red-hot iron when introduced is melted down in a shower of dazzling scintillations, forming oxide of iron.

Ordinary rust is also oxide of iron formed from the slow combustion of iron at atmospheric temperature, whilst the intense temperature of a mixture of carbon and pure oxygen in a state of combustion, as exemplified in the smith's forge, is only another degree of the same process. Phosphorus introduced amongst oxygen produces a volume of painfully brilliant light, and forms phosphoric acid.

The oxy-hydrogen light is produced by bringing equivalent quantities of oxygen and hydrogen gases into a burner and igniting them, when they evolve vivid combustion and intense heat, melting all common metals with great ease. Lime, however, resists its fusive power, and evolves a most brilliant light. A still more luminous light is produced by the action of electricity on two pieces of charcoal.

Nitrogen.

This body neither supports life nor combustion. It is lighter than air, and has no taste or smell. Its specific gravity is ·9736; one cubic foot at 32° weighs ·9736 ounce. Although nitrogen has some properties in common with carbonic acid, one of the products of perfect combustion, it has also dissimilar ones, besides being an elementary body, while carbonic acid is a compound of oxygen and carbon.

Carbon.

This is a finely divided pulverulent mineral body in its ordinary state, forming the basis of most fuels, and found in many different forms; as it is obtained by various processes—from oil lamps, as lampblack; from coal, as coke; and from wood, as charcoal. It is the mineral particles of carbon in a state of combustion, which render flame luminous from either gas, oil, or candles. Tallow or wax candles are a compound of carbon, oxygen, and hydrogen. The diamond is pure carbon in a crystalline state, possessing the singular property of reflecting all the light which falls upon it at an angle of about 24°, whilst artificial gems only reflect half that light.

Carbon unites with iron to form steel, and with hydrogen to form the common street gas, called carburetted hydrogen gas. Analysts tell us that the diamond and its converse, lampblack, are both pure carbon; and charcoal and coke are other well-known forms of carbon, obtained by burning them with a partial supply of air or oxygen. Coals are a compound of carbon, hydrogen, nitrogen, and oxygen. Carbon is considered as the next most abundant body in nature to oxygen. In the furnace the carbon of the fuel unites with the oxygen of the air to produce heat. If the supply of air is correctly regulated, there will be perfect combustion producing carbonic acid; but if the supply of air be deficient, combustion will be imperfect, and carbonic oxide produced.

Carbonic Acid Gas.

When air passes through a fire, carbonic acid gas is formed by the combustion of 16 parts of oxygen and 6 parts of carbon. Its specific gravity is 1·529. It is fatal to life, and it also extinguishes fire, as was shown by Mr. Gurney, who forced it into the burning Sauchie coal-mine, and put out a fire of about 26 acres area and 30 years' duration.

Carbonic Oxide.

This is a colourless, transparent, combustible gas, which burns with a pale blue flame, as may be seen at times on opening a locomotive fire-box door. Its presence in a furnace is evidence of imperfect combustion, from a deficient supply of air, as it indicates that only 8 parts of oxygen instead of 16 parts have united with 6 parts of carbon. As much more is required to produce complete combustion in the formation of carbonic acid.

Hydrogen.

Hydrogen is the source of all common flame, although it extinguishes a light plunged into it, but in doing so takes fire itself and burns at the edge of the vessel.

It is the lightest known body in nature, being 16 times lighter than oxygen, and is a permanent yet combustible gas, giving out much heat. It was discovered by Cavendish in 1766, and being 14½ times lighter than air, it is employed in balloons. In our gas establishments it is now distilled from coal in large quantities, and combined with carbon for illuminating streets, shops, and dwelling-houses. It is not itself noxious to life, but does not support it, and when combined with sulphur, it becomes explosive, and too frequently produces the most lamentable results in our coal mines. By passing a current of steam through a hot iron tube partly filled with filings, hydrogen gas is given off, and burns with a pale yellow flame.

Heat of Combustion.

The combustible elements concerned in the production of steam are hydrogen, carbon in its several primitive forms, and sulphur. The following are the results arrived at by Messrs. Favre and Silbermann, in their observations on the heat of combustion of these combustibles, and of a few others of a compound nature. The heat of combustion is given for one pound weight of the combustible, and is expressed in units of heat, the unit being that which is required to raise the temperature of one pound of water one degree Fahrenheit.

The equivalent quantities of water which would be evaporated from and at 212° Fahr. by the respective quantities of heat are added, for comparison, in a form more familiar to the engineer. These quantities of water are formed by dividing the units of heat by 965, which is the number of units of heat absorbed by water supplied at 212° Fahr., and evaporated at the same temperature.

One pound burned.	Units of heat.		Water evaporated from and at 212°.
Hydrogen	62,032	or	64·28 lbs.
Carbon (mean of several experiments) .	14,250	„	14·77 „
Sulphur	4,032	„	4·18 „
Carbonic oxide	4,325	„	4·48 „
Alcohol	12,929	„	13·40 „
Olefiant gas	21,343	„	22·11 „
Turpentine	19,534	„	20·24 „

The last four substances are compounds, and the last three consist wholly or chiefly of carbon and hydrogen. The total heating power of coal of average composition, according to Mr. D. K. Clark, amounts to 14,320 units. or 12·83 lbs. of water evaporated from 212° Fahr

Hydrogen, it is seen, stands pre-eminently at the head of the list for heating power, represented by the evaporation of 64¼ lbs. of water at 212° Fahr., by one pound of the gas, whilst carbon, the next in order, and the staple combustible element of fuels, has only a heating power represented by 14¾ lbs. of water. The more hydrogenous the fuel, therefore, the greater, in general, is its heating power. The element of hydrogen is, nevertheless, to a greater or less degree, neutralised by the other element, oxygen, when it is present as a constituent of the fuel; since the affinity of hydrogen for oxygen is superior to that of carbon, and the oxygen, saturated with hydrogen, is converted into aqueous vapour, and rises in this form from the fuel-bed, without having passed through the heat-giving process of chemical combination in the gaseous form. Thus it is that the more oxygenated the fuel, the less is its power of developing heat by combustion.

Process of Combustion in a Furnace.

For raising steam the process of combustion consists in evolving and completely consuming the combustible elements of either coal, coke, or other fuel employed to produce heat, which may be divided into four different stages of the process:

First stage.—Application of existing heat to evolve the constituent gases of the fuel. In coals this is principally carburetted hydrogen.

Second part.—Application or employment of existing heat to separate the carbon from the hydrogen.

Third part.—Further employment of existing heat to increase the temperature of the two evolved combustibles, carbon and hydrogen, until they reach the heat necessary for combination with the oxygen of the air. If this heat is not obtained, chemical union does not take place, and combustion is imperfect.

✓ Fourth and last part.—The union of the oxygen of the air with the carbon and hydrogen of the furnace, in their proper equivalents, when intense heat is generated by the exchange of the electrical heat in each, and light is also given off from the ignited carbon. Sir H. Davy estimated this heat as greater than the white heat of metals.

In the first three stages of combustion heat is absorbed by the fuel, and only in the last stage of the process is that absorption replaced with greatly increased effects.

When the chemical atoms of heat are not united in their proper equivalents, then carbonic oxide, carburetted hydrogen, and other combustible gases escape invisibly, with a corresponding loss of heat from the fuel. When the proper union takes place, then only steam, carbonic acid, and nitrogen escape, which, being the products of perfect combustion, are all incombustible, and also incapable of supporting combustion.

The principal products, therefore, of perfect combustion are—

Steam,	invisible and incombustible.
Carbonic acid,	invisible and incombustible.

The products of imperfect combustion are—

Carbonic oxide,	invisible but combustible.
Smoke,	partly invisible and partly incombustible.

Steam is formed from the hydrogen gas given out by the coals combining with its equivalent of oxygen from the air, in the ratio of 2 volumes of hydrogen to 1 of oxygen, or by weight as 1 to 8, as already explained.

Carbonic acid is formed from the carbon of the coals combining with its equivalent of oxygen from the air, in the proportion of 2 volumes of oxygen to 1 volume of carbon, or by weight as 16 to 6.

Carbonic oxide is formed from the carbonic acid first produced, receiving another volume of carbon in passing through the fire, which last volume of carbon is unconsumed, and forms the combustible carbonic oxide, whilst carbonic acid, having had its carbon consumed, is incombustible.

Smoke is formed from the hydrogen and carbon which have not received their respective equivalents of oxygen from the air, and thus pass off unconsumed. The colour of the smoke depends upon the carbon passing off in its dark pulverised state, but the quantity of heat carried away is not dependent upon the carbon alone, but also upon the invisible but combustible gases (hydrogen and carbonic oxide), so that whilst the colour may indicate the amount of carbon in the smoke, it does not indicate the amount of heat lost: hence the smokeless locomotive, in burning coke, may lose more heat in this way than is lost from the imperfect combustion of coals in stationary-engine furnaces.

Besides the demands of the carbon for the oxygen admitted to the furnace, the hydrogen evolved also requires its equivalent. But where there is no provision for the proper supply of oxygen to such gases, it is evident that a portion of the combustible gases evolved must pass off unconsumed.

A practical and familiar instance of imperfect combustion is exhibited when a lamp smokes, and the unconsumed carbon is deposited in "blacks" all round it. When the evolution of carbon is lessened by lowering the wick to meet the supply of oxygen, the carbon is all consumed and the smoke ceases. What takes place with a lamp also occurs in a furnace, so that the proper supply of air is a primary consideration, both as regards its quantity and its mode of admission to a fire, for both affect the economical results.

The economical generation of heat is therefore a process entirely distinct from the use made of that heat afterwards, just as the generation of steam is an entirely different question from its employment in an engine.

Combustion may be perfect, but absorption of heat by a boiler may be inferior, and consequently evaporation of water bear a low ratio to the fuel consumed. To arrange the construction of a boiler with rapidly absorbing materials is the principle aimed at by our best boiler-makers, to obtain increased evaporative power.

Summary of the Chemistry of Combustion.

Begin with coal as the staple fuel, adopting Mr. D. K. Clark's estimate of the average composition of English coal, namely—

Carbon	about	80	per cent.
Hydrogen	„	5	„
Sulphur	„	$1\frac{1}{4}$	„
Oxygen	„	8	„
Nitrogen	„	$1\frac{1}{3}$	„
Ash	„	4	„
	About	100	

Now one pound of hydrogen unites with and requires 8 lbs. of oxygen for its combustion; measuring by volume, one cubic foot of hydrogen requires just half a cubic foot of oxygen for combustion, the product being steam, aqueous vapour, or water. Oxygen is sixteen times as weighty as hydrogen, and so hydrogen combines with eight times its weight and but half its volume of oxygen. In round numbers, 1 lb. of hydrogen is 200 cubic feet in bulk, at 62° Fahr., and the combining volume of oxygen is 100 cubic feet.

Turning to carbon, which is the basis of all fuels, 1 lb. of carbon unites with $2\frac{2}{3}$ lbs., or 32 cubic feet, of oxygen, for its complete combustion, forming carbonic acid.

Atmospheric air is, as before stated, composed of oxygen and nitrogen, in the proportion of 1 lb. of oxygen to $3\frac{1}{2}$ lbs. of nitrogen; or, by volume, 1 cubic foot of oxygen to 4 cubic feet of nitrogen. Nitrogen, being a neutral gas in combustion, is present as a diluent simply; and for every cubic foot of oxygen required in combustion, 5 cubic feet of air must be supplied.

It follows that, for the combustion of 1 lb. of hydrogen, 500 cubic feet of air are required, and for the complete combustion of 1 lb. of carbon, 160 cubic feet of air are required.

To make the estimate complete, it may be added, that a pound of sulphur requires 60 cubic feet of air, and the total quantity of air chemically consumed in the combustion of 100 lbs. of coal of average composition, is therefore as follows :—

80 lbs. of carbon × 160 = 12,800 cubic feet.
5 „ hydrogen × 500 = 2,500 „
1½ „ sulphur × 60 = 75 „

Total air per 100 lbs. 15,375 cubic feet.
Or in round numbers, 16,000 cubic feet.

As, further, the fixed carbon, or the coke which remains after the volatile portions of the fuel are driven off, averages 60 per cent, or 60 lbs. per 100 lbs. of coal, the proportional quantities of air chemically required for the volatile and fixed portions respectively may be simply ascertained. Sixty pounds of carbon require $160 \times 60 = 9{,}600$ cubic feet of air—say 10,000 cubic feet, and the proportions are therefore as follows :—

Volatile elements	6,000 cubic feet.
Fixed element, or coke	10,000 „
Total air per 100 lbs. . . .	16,000 cubic feet.

Or 160 cubic feet of air per pound of coal. Of this supply, three-eighths are consumed by the volatile elements and five-eighths by the fixed element. It is easily conceivable, therefore, in view of so large a demand in behalf of the volatile or smoke-making elements, that the complete combustion of these elements is a matter involving some care to effect the ultimate mixture of the gases and air, which is necessary to effect the complete combustion of the gases.

In order to prevent the formation and discharge of smoke, it is necessary to admit a greater quantity of air to the furnace than is chemically consumed, so that each particle of gaseous combustible matter may be supplied with its due equivalent of oxygen. The proportion of such surplus air may, in ordinary furnaces, amount to as much as the air chemically consumed, and thus upwards of 30,000 cubic feet of air may be needed for the combustion of 100 lbs. of coal, or 300 cubic feet for one pound.

Temperature of Combustion.

The temperature of the products of combustion at the instant of their formation varies, of course, with the quantity of air in dilution. Professor Rankine estimates the temperature to be as follows :—

	Carbon.	Olefiant Gas.
Fuel, undiluted with air	4,580°	5,050°
If diluted with an excess of half the air consumed	3,215	3,515
If diluted with an excess equal to all the air consumed	2,440	2,710

CHAPTER VI.

FUEL—COAL.

THERE are very great individual differences in the chemical composition and properties *of coals*, and their varieties are very numerous. The proportion of fixed carbon in coal ranges from 30 to 93 per cent.; of hydro-carbons from 5 to 58 per cent.; of water, or oxygen and hydrogen in the proportions to form water, from a mere trace to 27 per cent.; and of ash from 1½ to 26 per cent. The varieties of coal may be arranged in five classes:—1. Anthracite, or blind coal, consisting almost entirely of free carbon; 2. Dry bituminous coal, having from 70 to 80 per cent. of carbon; 3. Bituminous coking coal, with from 50 to 60 per cent. of carbon; 4. Long flaming or cannel coal, differing from the last in containing more oxygen, and in some varieties it does not cake; 5. Lignite, or brown coal, containing 27 to 50 per cent. of carbon.

The preceding remarks on heat and combustion will be rendered practically available in selecting coals for particular purposes, by the following tabular arrangement of 37 varieties of Welsh, 19 of Newcastle, 28 of Lancashire, 8 of Scotch, 1 of Irish, 8 of Derbyshire, 9 of Van Diemen's Land, 2 of Patagonian, 3 of Bornean, 6 of Chilian, 5 from different localities, and 42 of American coals, with 6 of patent fuels. With the exception of the American varieties, the 132 to the varieties are abstracted from the able reports of Sir H. de la Beche, F.R.S., and Dr. Lyon Playfair, F.R.S., "On Coals suited to Steam Navy," begun in 1846, and the last report issued in April, 1851. The American government had instituted a similar inquiry into coals, and a copy of their report coming into the hands of Mr. Hume, M.P., that able public man lost no time in forwarding it to the Lords of the Admiralty (10th June, 1845), suggesting that a similar course should be pursued to ascertain "the best coals for the naval steamers of this country." This was promptly undertaken by the Admiralty, who on the 22th June issued instructions to ascertain how the "inquiry could be conducted with the greatest effect."

The properties sought to be determined by these experiments were, briefly, 1st. Evaporative value; 2nd. Mechanical structure; 3rd. Combustible character; and 4th. Chemical composition.

Evaporative Power.

To Smeaton we believe is due the merit of the first systematic attempt to define the comparative effect of different coals. In 1769 he constructed an experimental engine, having a cylinder nearly 10 inches diameter and 3 feet stroke. The boiler consumed 55 lbs. of coals per hour, and evaporated 6·14 lbs. of water under a pressure of 7·8 lbs. per square inch for each pound of coals.

Taking the Halston coals from Yorkshire as evolving an evaporative power of 100, he found the useful ratio of the others used by him as under:—

Halston	100	Welsh	110
Berwick Moor	86	Newcastle	120
Middleton	110	Cannel	130

Coke $\frac{5}{8}$ of that of the coal from which it was made.

The quantity of coke produced from coals he found to be about 66 per cent., or nearly the same as at present. Although recent investigations have placed the Welsh coals at the top of the practical evaporative test, yet those early experiments bear ample evidence of the care with which they had been made. Under his best boilers, Smeaton found 7·88 lbs. of water evaporated by 1 lb. of coals, from 212°, as the evaporative value of Newcastle coals. Watt's improved boiler gave 8·62 lbs., and this was long considered the standard till the Cornish engineers gradually increased it to 10·74 lbs. in 1840, and in 1846 to 12·89 lbs. of water evaporated by 1 lb. of coals.

Mr. Wicksted gave the following comparative ratios of practical or realised evaporation :—

Name of Fuel.	Water evaporated from 52° by 1 lb. of fuel.
	lbs.
Welsh, best	9·493
Anthracite	9·014
Newcastle, best small	8·524
„ average	8·074
Welsh, average	8·045
Gas coke	7·908
Half coke and half Newcastle small	7·897
Half Welsh and half Newcastle	7·865
Half Newcastle and half Derbyshire	7·710
Newcastle, average of large	7·658
Derbyshire	6·772
Blythe Main, Northumberland	6·600

The value given here for anthracite is, however, much less than that found by Messrs. Josiah Parkes and Charles Manby, in 1840, from a series of experiments made on anthracite as a steam fuel. With a boiler having 340 square feet of heating surface, the result gave 13·48 lbs. of water as the evaporative value of 1 lb. of the fuel, compared with 11·89 lbs., the then highest recorded duty of a Cornish boiler, having 961 square feet of heating surface, or 13 per cent. in favour of the anthracite with a small boiler. What the difference would have been in boilers of equal heating areas they had not the means to decide, but they considered 13 per cent. as the minimum difference of value between anthracite and the best Welsh coals.

The subject was one of growing importance, and, under the sanction of the Government, it was ably investigated in the following manner.

The evaporative value was arrived at by taking the mean of three separate days' trials with each fuel in a small Cornish boiler 12 ft. long, 4 ft. diameter, with inside flue of 2 ft. 6 in. diameter and flat ends. The fire was placed in one end of this flue, and the current of heated gases returned by "split" flues round each side of the boiler to the front, where they united and passed under the boiler to the chimney. During two of the trials the pressure on the safety valves was 1 lb. per square inch, and it was usually 3 lbs. during the third trial.

As the comparative weight to bulk of water varies with its temperature, the necessary allowances were made in reducing the results of the trials.

The heating effect of the wood used to light the fires was first experimentally determined, and its effect for each trial by the following Table, based on Regnault's experiments, was deducted from the total evaporation of both wood and coals.

TABLE No. X.

SPECIFIC AND DIFFUSED HEAT OF WATER AND STEAM FROM 32° TO 446° FAHR.

Air Ther. Cent.	Mercurial. Cent.	Number of Unities of Heat abandoned by one kilo. of water in descending from T to 0°.	Air Ther. Fah.	Mercurial Fah.	Number of Unities of Heat contained in one pound of water at T°.	Mean specific Heat of Water between 0° and T cent. or between 32° and T. Fah.	Specific Heat of Water from T to T+*d* T.	Latent Heat of Steam saturated to the temperature T.	
								Cent.	Fah.
°	°		°	°					
0	..	0·000	32	..	32·000	..	1·0000	606·5	1091·7
10	..	10·0	50	..	50·003	1·0002	1·0005	599·5	1079·1
20	..	20·010	68	..	68·018	1·0005	1·0012	592·6	1066·7
30	..	39·026	86	..	86·046	1·0009	1·0020	585·7	1054·2
40	..	40·051	104	..	104·091	1·0013	1·0030	578·7	1041·6
50	50·2	50·087	122	122·36	122·156	1·0017	1·0042	571·6	1028·9
60	..	60·137	140	..	140·246	1·0023	1·0056	564·7	1016·4
70	..	70·210	158	..	158·381	1·0030	1·0072	557·6	1003·7
80	..	80·282	176	..	176·507	1·0035	1·0089	550·6	991·1
90	..	90·381	194	..	194·685	1·0042	1·0109	543·5	978·3
100	100·0	100·500	212	212·0	212·900	1·0050	1·0130	536·5	965·7
110	..	110·641	230	..	231·153	1·0058	1·0153	529·4	952·9
120	..	120·806	248	..	249·450	1·0067	1·0177	522·3	940·1
130	..	130·997	266	..	267·794	1·0076	1·0204	515·1	927·2
140	..	141·215	284	..	286·187	1·0087	1·0232	508·0	914·4
150	150·0	151·462	302	302·0	304·623	1·0097	1·0262	500·7	901·2
160	..	161·741	320	..	323·133	1·0109	1·0294	493·6	888·5
170	..	172·052	338	..	341·693	1·0121	1·0328	486·2	875·1
180	..	182·398	356	..	360·316	1·0133	1·0364	479·0	862·2
190	..	192·779	374	..	379·002	1·0146	1·0401	471·6	848·9
200	200·0	203·200	392	392·0	397·760	1 0160	1·0440	464·3	835·7
210	..	213·660	410	..	416·588	1·0174	1·0481	456·8	822·2
220	..	224·162	428	..	435·480	1·0189	1·0524	449·4	808·9
230	..	234·708	446	..	454·474	1·0204	1·0568	441·9	795·4

Corrections for variations of temperature of the feed-water were made.

Comparative Evaporative Performance of different Boilers.

To determine how far the experimental boiler gave results as compared with the best Cornish boilers, Mr. Phillips went to the Par Consols mine, and had 119,700 lbs. of water evaporated from 92° by 11,730 lbs. of coal; equal to 10,004 lbs. of water by 1 lb. of coals, or 11,428 lbs. from 212°.

The Mynydd Newydd experimental coals had the nearest chemical composition to those used in the above trial, and only evaporated 9·52 lbs. of water per lb. of coals from the experimental boiler, being very nearly 20 per cent. less than in the larger boilers. The ratios therefore of realised evaporation in the tables multiplied by 1·1995 will give the value for boilers of the same evaporating power as those at the Par Consols mine.

From this it will be noticed that the tabulated evaporative results are only comparative, under the same boiler and conditions; for the precise value would vary according to the merits of the particular boiler employed.

Coking Quality of Coals.

The quantity of coke in the several varieties was ascertained by subjecting a portion of them in a crucible to a white heat for several hours, and weighing the coke left in the crucible.

During the experiments only one sample of locomotive coke was sent for investigation. This was made by Messrs. Cory, of New Barge Wharf, Lambeth, from Andrews's House Tanfield coals, in a plain circular oven, having a brick-built door, and the coke cooled with water in the oven, yielding about 65 per cent. of coke from the coals used. To test the practical with the theoretical effects of coking, three separate trials were made in the crucible on coals from the same mine, which gave a mean yield of coke of 65·13 per cent. of the coals, which was regarded as satisfactory evidence of the practical return of coke by Messrs. Cory's process of producing hard coke. Although in coking the weight of the fuel decreases 35 per cent., the bulk appears to gain about 11·7 per cent., as seen in the table. In one trial under the experimental boiler with the draught increased by blowing the steam into the chimney, the coke evaporated about 20 per cent. less water for equal weights than the coals it was made from. The same increased blast was used both with the coke and coal to give comparative results, and the following statement of this trial will show the precautions taken to ensure accuracy with all the experiments; though it has since been established that coke of good quality is as powerful for evaporation as the average of coals.

TABLE No. XI.

COMPARATIVE EVAPORATION OF WATER BY COALS AND COKE UNDER THE SAME CONDITIONS.

Particulars.	Coals.	Coke.
Fire lighted	10 h. 0 m.	9 h. 0 m.
Steam up	11 h. 0 m.	10 h. 15 m.
Wood used	10 lbs.	10 lbs.
Initial temperature of water in boiler	192°	203°
Temperature of water in tank	50° mean	50° mean
Barometer	29·7 mean	29·65 mean
Extremes of external thermometer	32°—56°	36°—56°
Extremes of internal thermometer	58°—68°	52°—65°
Dew point	48° mean	461 mean
Area of damper open	168 in.	168 in.
Fuel consumed	2119 lbs.	2184 lbs.
Ashes left	41 lbs.	94 lbs.
Combustible matter in ashes in general from about 20 to 70 per cent., averaging about 38 per cent.		
Cinder left	12 lbs.	none
Combustible matter in cinder in general, from about 20 to 80 per cent., averaging about 55 per cent.		
Clinker	42 lbs.	25 lbs.
Average soot in flues	none	none
Combustible matter in soot in general, from about 55 to even 90 per cent., averaging about 70 per cent.		
Water evaporated	17895 lbs.	15275 lbs.
Water evaporated from 212° by 1 lb.	9·91 lbs.	7·91 lbs.
Burnt per hour per square foot of grate	12·4 lbs.	12·84 lbs.
Duration of experiment	34 h.	34 hours
Specific gravity	1·264	
Mean weight of 1 cubic foot	52·1	30·
Economic weight per 1 ton	42·99	74·66
Cohesive power		
Pressure of steam blowing off	3 lbs.	3 lbs.
Evaporation per hour	526·3 lbs.	449·2 lbs.
Fuel per hour	62·3 lbs.	66·2 lbs.*

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* The per-centage of combustible matter in the ashes, cinders, and soot is not from these experiments, but an average for general reference.

According to this table, 1 lb. of coals evaporated 9·91 lbs. of water, and 1 lb. of coke only 7·91 lbs., or 20·1 per cent. less than the coals. The quantity evaporated in a given time was also greater by 77 lbs. per hour for the coals.

The increased draught also increased the evaporative results of the coals 5½ per cent. over the previous trial with the ordinary flue draughts only. The evaporative-*power* column includes the estimated loss from the unconsumed combustible matter in the residue. The *realised* column was what was actually obtained during the trials.

Mechanical Structure.

The general appearance of the coal was noted, and its comparative bulk to weight for stowage was ascertained by filling a box, of 6 cubic feet capacity, with each variety tried, and carefully noting the weight per cubic feet. This weight, multiplied by the realised ratio of evaporation per lb., gives the evaporative power in 1 cubic foot of the particular coals. The cohesive property was found by placing 100 lbs. of suitable-sized firing pieces, which would not pass through a sieve of 1-inch mesh, in a vertical wooden cylinder, 3 feet diameter and 4 feet high. This cylinder had internal angular shelves, which on its being turned round on its axis, carried the coals upwards and let them fall to the bottom, which more or less broke them according to their natural cohesion. Each variety was subjected to two trials of 50 revolutions each time, and then the mean number of pounds of coals which would not pass through the 1-inch mesh sieve is given in the tables as the comparative cohesion per cent. to resist ordinary attrition.

The ordinary hygrometric water in coals was determined by drying them at a temperature of 212°, and has been placed under this heading as more allied thereto than to chemical union, that more extended observation on the effect of such water from fuel on the practical results might be noticed.

Combustible Character.

The combustible peculiarities were noted from observation and analyzation of the residue arising from combustion. The ease or difficulty of lighting, the draught best suited, the rapid or slow combustion, the coking or open burning, the amount of attention from the stoker, the quantity of smoke, ashes, cinders, and clinkers, with the ratios of unconsumed combustible matter in the residue, were all noted.

Of the residue, the whole per-centage is given, and the clinkers separately. Ashes are no doubt troublesome when in large quantities, but these may be approximately ascertained by the chemical analysis. Clinkers are, however, more troublesome, and fusible ones which adhere to the fire bars particularly so in obstructing the draught. In the Table these are marked ad. for adhesive. In locomotive furnaces the formation of clinkers is very prejudicial to the generation of steam, and Goldsworthy Gurney, Esq., from his unpleasant experience of these effects on his common-road steam carriages, calls them "fire-eaters."

The per-centage of combustible matter in the residue varies in proportion to the quantity of small coals which falls through the grate, and generally the increase of a per-centage of residue would indicate an increased per-centage of combustible matter also, over the per-centage when the fuel was fairly consumed, and the residual matter comparatively small.

It will be noticed that the Newcastle coals so generally employed for domestic use in London are of a caking, smoky character, which, however suitable the caking is for the house or forge fire, is not so suitable for steam furnaces.

An experiment with 7 lbs. of Pyle coals in their ordinary state, and 7 lbs. wet with water, showed a decided difference on a common house fire in coking in favour of the wet coals, but was found to operate the reverse way in evaporating water, for the dry coals kept a more open fire, and evaporated 2 lbs. more water in 6 hours. A further experiment by immersing 20 lbs. of these coals in water for 24 hours showed that they absorbed no appreciable quantity of water but that due to their wet surfaces, and when these were dry no perceptible difference in weight was detected.

Chemical Composition.

The chemical analysis was carefully made from a fair average sample of the coals as mined, checked by an analysis of pure coal from the same sample. Coals in their ordinary state contain more or less shaly, whitish, dull-blackish, extraneous matter or veins of iron pyrites, besides the pure coals, which decrease the evaporative value whilst they increase the duty of the stoker and per-centage of residual matter. An analysis therefore of the pure coal, or even the specific gravity of the pure coal, would be no just criterion of the practical composition or practical weight per cubic foot. The analysis therefore of the average sample only *as mined* is given under this heading, as the weight per cubic foot was given under the heading of mechanical structure.

The following Tables show the various substances found in Coals and their Ashes by analysis :—

TABLE No. XII.

PRODUCTS FROM DESTRUCTIVE DISTILLATION OF COALS.

Name of Coal.	Coke.	Tar.	Water.	Ammonia.	Carbonic Acid.	Sulph. Hydrogen.	Olefiant Gas and Hydro-carbon.	Other inflammable Gases.
Craigola . . .	85·5	1·2	3·1	0·17	2·79	traces	0·23	7·01
Anthracite (Jones & Co.) . .	92·9	none	2·87	0·20	0·16	0·14	..	8·93
Old Castle Fiery Vein	79·9	5·86	3·39	0·35	0·44	1·12	0·27	9·77
Ward's Fiery Vein .	..	1·80	3·01	0·24	1·80	0·21	0·21	
Binea . . .	88·10	2·08	3·58	0·08	1·68	0·09	0·31	4·08
Llangennech . .	83·69	1·22	4.07	0·08	3·21	0·02	0·43	7·28

TABLE No. XIII.

Incombustible Matters in Coal Ashes.

Name of Coal.	Silica.	Alumina and Oxide of Iron.	Lime.	Magnesia.	Sulphuric Acid.	Phosphoric Acid.	Total per centage.
Pontypool . .	40·00	44·78	12·00	trace	2·22	0·75	99·75
Bedwas . .	27·87	56·95	5·10	1·19	7·23	0·74	98·08
Warlich's pat. fuel	25·20	57·30	6·90	trace	7·85	..	99·41
Porthmawr . .	84·21	52·00	6·199	0·659	4·12	0·633	97·821
Ebbw Vale . .	53·00	35·01	3·94	2·20	4·89	0·88	99·92
Fordel Splint .	37·60	53·00	3·73	1·10	4·14	0·88	99·45
Wallsend Elgin .	61·66	24·42	2·62	1·73	8·38	1·18	99·99
Coleshill . .	59·27	29·09	6·02	1·35	3·84	0·40	99·97

Calorific Value.

This was determined chemically, and also practically, by enclosing 5 grains of finely powdered coal, with 2000 grains of litharge, in an air-tight crucible, and weighing the "button" of lead melted down. The tables give the mean of three separate trials with each fuel. Estimating the heating value of carbon as 13,628, the tabular value multiplied by ·45, gives the lbs. of water which 1 lb. of each fuel should raise from 30° to 212° where the structure of the coals is favourable. As this is not always so, we have preferred the litharge value for practical reference, since the chemical value is from 10 to 12 per cent. higher on the average than the litharge value.

TABLE No. XIV.—COMPARATIVE COST, MECHANICAL, COMBUS OF THIRTY-SEVEN VARIE

NAME OF COAL.	COST, per ton, at the		MECHANICAL STRUCTURE.				COMBUSTIBLE		
	Pit.	Nearest Seaport.	Bulk per ton, cubic feet.	Weight per cubic foot—lbs.	Weight of Water in Coals, per cent.	Cohesion of large Coals, per cent.	Light.	Draught required.	Burns.
Aberaman, Merthyr	2nd sample	10s.	45·80	48·9	·41	74·	ordinary	quick	freely
„ „	1st sample		43·57	51·4			ord.	quick	freely
Ebbw Vale			42·26	53·3	1·34	45·	easily	ord.	clear
Thomas's Merthyr			42·26	53·	1·42	57·5	ord.	ord.	freely
Duffryn			42·09	53·22	1·13	56·2	readily	ord.	freely and clear
Nixon's Merthyr		10s.	43·32	51·7	1·22	64·5	difficultly	quick	stg. flame
Binea	7s. to 10s.		39·24	57·08	3·58	51·2	slowly	ord.	freely
Bedwas			44·32	50·5	1·28	54·	easily	ord.	freely
Hill's Plymouth Works		8s. to 9s.	43·74	51·2	1·26	64·	slowly	quick	steadily
Aberdare Co.'s Merthyr			45·43	49·3	1·40	74·5	ord.	ord.	freely
Gadly 9-ft. seam			40·87	54·8	1·44	76·	ord.	strong	stg. flame
Resolven		10s.	38·19	58·66	1·55	35·	easily	ord.	strng. open flame
Mynydd Newydd			39·76	56·33	·61	58·7	easily	ord.	cake and obs.
Abercairn			44·53	50·3	7·11	54·5	easily	ord.	cake and obs.
Anthracite, Jones & Co.			38·45	58·25	2·87	68·5	diff.	quick	inten. ht.
Ward's Fiery Vein	6s. 3d. to 9s.		39·00	57·433	3·01	46·5	easily	ord.	freely and clear
Neath Abbey			37·77	59·3	1·02	50·	easily	ord.	freely
Craigola			37·23	60·166	3·1	49·3	easily	ord.	freely
Gadly 4-ft. seam			43·41	51·6	1·24	68·5	ord.	strong	stg. flame
Machen Rock Vein			46·56	48·1	2·5	52·5	easily	ord.	clear
Birch Grove Craigola			43·92	51·	1·51	59·	ord.	ord.	clear and free
Llynvi			42·02	53·3	1·13		ord.	ord.	steadily
Cadoxtan		6s. 6d. to 10s.	38·55	58·1	1·52		diff.		badly
Old Castle Fiery Vein	6s. 6d. to 9s.		43·99	50·916	3·	57·7	easily	ord.	freely and expl.
Vivian & Son's Mirfa		7s. 6d.	46·76	47·9	·63	54·0	easily	moderate	cake and obs.
Llangennech			39·34	56·93	4·07	53·5	ord.	ord.	slowly
Three-quarter Rock Vein			39·72	56·388	1·67	52·7	easily	strong	cake mod.
Pentrepoth			38·80	57·72		46·5	diff.	ord.	
Cwm Frood Rock Vein		9s. 6d.	40·52	55·277	1·12	72·5	ord.	ord.	smoky
Cwm Nanty Gros			40·	56·	·9	55·7	easily	ord.	moderate
Brymbo Main		6s. 8d.	47·65	47·	4·50		quickly	ord.	clear
Vivian & Son's Rock Vein		7s. 6d.	45·80	48·9	1·45	70·5	quickly	mod. qk.	cake and obs.
Coleshill		8s. 6d.	42·26	53·	4·91	62·	quickly	ord.	freely
Brymbo Two-yard		7s.	46·76	47·9	3·35	79·5	easily	ord.	clear
Rock Vawr		8s. 6d.	40·72	55·	2·33	65·5	easily	ord.	moderate
Porth-Mawr Rock Vein		8s. to 9s. 6d.	42·02	53·3	1·7	62·	easily	ord.	freely
Pontypool		9s. 6d.	40·21	55·7	1·6	57·5	easily	ord.	freely
Pentrefelin	8s. 9d.		38·65	66·166	1·33	52·7	diff.	ord.	bad hes. obs.

TIBLE, EVAPORATIVE, COKING, AND CHEMICAL PROPERTIES TIES OF WELSH COALS.

CHARACTERISTICS.					EVAPORATIVE VALUE.					CHEMICAL COMPOSITION.						
					Steam raised		Water evaporated from 212° by 1 lb. of Coals.									
Attention required.	Smoke.	Clinkers, per ton, Clinkers, lbs.	Residue of Clinkers, Ashes, Cinders, and Soot—per cent.	Calorific Value of 5 grains in Melting Lead—grains.	In Time—mean.	From temp. of Fah.	Power of—lbs.	Realized—lbs.	Rate of, per hour—lbs.	Carbon—per cent.	Hydrogen—per cent.	Oxygen—per cent.	Nitrogen—per cent.	Sulphur—per cent.	Ashes—per cent.	Coke—per cent.
ordinary	little	13·3	6·5	159·9	22	198		10·75		90·94	4·28	·94	1·21	1·18	1·45	85·
ord.	little	13·0	7·38	159·9	23	209	10·04	9·53								
careful	moderate	9·5	5·87	159·9	43	187	10·64	10·21	460·22	89·78	5·15	·39	2·16	1·02	1·50	77·5
little	little	3·9	9·03	164·8	20	209	10·72	10·16	520·8	90·12	4·33	2·02	1·00	·85	1·68	86·53
little	none	none	7·8	150·0			11·80	10·14	409·33	88·26	4·66	·60	1·45	1·77	3·26	84·3
little	little	5·7	11·31	166·	38	209	10·7	9·96	511·4	90·27	4·12	2·53	·63	1·20	1·25	79·11
little		none	8·22	158·2	29	216	10·3	9·94	486·95	88·66	4·63	1·03	1·43	·33	3·96	88·10
little	little	22·9	4·79	141·	26	197	9·99	9·79	476·96	80·61	6·01	1·5	1·44	3·5	6·94	71·7
careful	little	7·5	7·01	170·3	42	195	10·18	9·75	531·6	88·49	4·0	3·82	·46	·84	2·39	82·25
little	little	9·8	8·38	170·6	58	193	10·27	9·73	489·5	88·28	4·24	1·65	1·66	·91	3·26	85·83
careful	none	6·0	17·05	170·8	27	208	10·46	9·56	517·3	86·18	4·31	2·21	1·09	·87	5·34	86·54
careful	little	none	4·71	160·8	30	198	10·44	9·53	390·25	79·33	4·75	in ash.	1·38	5·07	9·41	83·9
much	much	57·2	8·28	151·7	30	208	10·59	9·52	470·69	84·71	5·76	3·52	1·56	1·21	3·24	74·8
much	mod.	20· adhes.	4·83	153·8	12	207	9·63	9·47	480·	81·26	6·31	9·76	·77	1·86	2·04	6·84
careful	none	little	9·58	167·4	110	194	9·7	9·46	409·37	91·44	3·46	2·58	·21	·79	1·52	92·9
ord.	little	54·6	7·44	157·3	48	178	10·6	9·40	529·9	87·87	3·93	in ash.	2·02	·83	7·04	..
frequent	much	19·2 adhes.	5·44	156·0	52	155	9·65	9·38	546·1	89·04	5·05	..	1·07	1·[illegible]0	3·55	61·42
ord.	little	30·7	9·27	160·4	25	209	9·66	9·35	441·48	84·87	3·84	7·19	·41	·45	3·24	85·5
careful	none	11·6	20·54	171·2	35	202	10·73	9·29	400·	88·56	4·79	..	·88	1·21	4·88	88·23
ord.	little	12·4	5·26	153·3	22	205	9·43	9·23	488·75	71·08	4·88	17·87	·95	1·37	3·85	65·2
ord.	little	28·6 adhes.	9·89	166·3	17	209	9·64	9·22	507·5	84·25	4·15	5·58	·73	·86	4·43	85·1
ord.	little	36·	9·07	161·2	30	202	9·58	9·19	399·5	87·18	5·06	2·53	·86	1·33	3·04	72·94
much	none	34·76 adhes.	17·63	158·	105	190	9·07	8·97	344·16	87·71	4·34	1·58	1·05	1·75	3·57	82·0
ord.	little	none	6·57	157·1	87	162	..	8·94	464·3	87·68	4·89	3·39	1·31	·09	2·64	79·8
constant	much	18· adhes.	5·29	155·7	22	199	9·11	8·92	421·25	82·75	5·31	4·64	1·04	·95	5·31	67·1
ord.		66·4	11·04	163·3	25	203	9·2	8·86	373·22	85·46	4·20	2·44	1·07	·29	6·54	83·69
ord.	much	54·3	7·36	133·1	23	218	..	8·84	486·86	75·15	4·93	5·04	1·07	2·85	10·96	62·5
careful	little	80·	10·47	155·8	62	198	8·98	8·72	381·5	88·72	4·50	3·24	·18	..	3·36	82·5
ord.	much	38·5	7·8	141·5	28	215	9·38	8·70	379·80	82·25	5·84	3·58	1·11	1·22	6·	68·8
careful	little	23·3	5·44	148·4	27	205	8·82	8·42	404·16	78·36	5·59	5·58	1·86	3·01	5·6	65·6
little	much	10·7	5·12	151·8	17	198	8·56	8·36	435·83	77·87	5·09	9·52	·57	2·73	4·22	55·4
much	considbl.	30·1 adhes.	4·75	150·	10	209	8·19	8·08	492·5	79·09	5·20	8·34	·66	2·41	4·30	58·6
ord.	considbl.	39·5	7·78	130·7	22	205	8·34	8·	406·41	73·84	5·14	8·29	1·47	2·34	8·92	56·0
little	much	19·5	5·6	147·5	17	189	7·91	7·85	441·66	78·13	5·53	8·02	·54	1·88	5·90	56·2
ord.	little	38· adhes.	5·92	144·6	23	198	7·88	7·68	397·5	77·98	4·39	8·55	·57	·96	7·55	62·5
ord.	much	25·9	9·54	150·5	32	193	7·75	7·53	347·44	74·70	4·79	3·60	1·28	·91	14·72	63·1
constant	much	15·	12·63	137·3	17	207	8·04	7·47	250·4	80·70	5·66	4·38	1·35	2·39	5·52	64·8
ord.	mod.	28·6	27·7	152·6	127	162	7·4	6·36	247·24	85·52	3·72	4·55		·12	6·09	85·0

TABLE NO. XV.—COMPARATIVE COST, MECHANICAL, COMBUS OF NINETEEN VARIETIES OF THE NEWCASTLE

NAME OF COAL.	COST, per ton, at the		MECHANICAL STRUCTURE.				COMBUSTIBLE		
	Pit.	Nearest Seaport.†	Bulk per ton, cubic feet.	Weight per cubic foot—lbs.	Weight of Water in Coals, per cent.	Cohesion of large Coals, per cent.	Light.	Draught required.	Burns.
Willington		6s.	42·1	53·2	1·11	43·	difficultly	ordinary	cakes and obs.
Andrews' House, Tanfield *		5s. 6d.	42·99	52·1	6·58		easily		cakes and obs.
„ „ Coke			74·66	30·				strong	
Bowden Close		6s.	44·26	50·6	1·33	38·5	ordinary	ord.	cakes and obs.
Haswell Wallsend		9s. 3d.	47·25	47·4	4·08	73·	ord.	ord.	cakes and obs.
Newcastle Hartley	7s.		44·35	50·5	1·38	78·5	diff.	strong	
Hedley's Hartley			43·07	52·	1·46	85·5	easily	quick	slowly
Bates West Hartley		8s.	44·13	50·8	9·28	69·5	ord.	mod. qk.	mod. free
West Hartley Main		7s. to 7s. 6d.	45·80	48·9	6·76	79·	easily	ord.	rapidly
Buddle's West Hartley		8s.	44·09	50·6	7·24	80·	ord.	mod. qk.	freely
Hasting's Hartley		7s. 6d.	46·18	48·5	7·88	75·5	easily	ord.	freely
Carr's Hartley		7s. 6d.	46·86	47·8	5·60	77·5	easily	ord.	mod.
Davison's West Hartley		7s. 6d.	46·96	47·7	6·19	76·5	easily	ord.	freely
North Percy Hartley		8s.	45·62	49·1	8·41	60·	easily	ord.	freely
Haswell Coal Company's Steamboat Wallsend		8s.	45·25	49·5	1·14	79·5	easily	ord.	freely for a time
Derwentwater Hartley		6s. 6d.	46·44	50·4	12·52	63·5	easily	ord.	rapid
Broom Hill	3s. 4d.		42·67	52·5	9·31	65·7	easily	mod. qk.	dull flame
Original Hartley		7s. 6d.	45·62	49·1	8·11	80·	easily	ord.	rapidly
Cowpen and Sidney's Hartley		7s.	46·76	47·9	10·17	74·	easily	ord.	freely

* 1 lb. of Coals with ordinary draught evaporated 9·39 lbs. at the rate of 351·2 lbs. per hour.
1 lb. „ uneven draught „ 9·91 lbs. „ 526·3 lbs. „
1 lb. of Coke „ „ „ 7·91 lbs. „ 449·3 lbs. „

Newcastle Coals are said to have been first mined or "dug," during the reign of Henry III. in 1230.

TIBLE, EVAPORATIVE, COKING, AND CHEMICAL CHARACTERS
DISTRICT COALS AND ONE SAMPLE OF COKE.

CHARACTERISTICS.					EVAPORATIVE VALUE.					CHEMICAL COMPOSITION.						
					Steam raised		Water evaporated from 212° by 1 lb. of Coals.									
Attention required.	Smoke.	Clinkers, per ton, Adhesive, lbs.	Residue of Clinkers, Ashes, Cinders, and Soot—per cent.	Calorific Value of 5 grains in Melting Lead—grains.	In Time—mean.	From temp. of Fah.	Power of—lbs.	Realized—lbs.	Rate of, per hour—lbs.	Carbon—per cent.	Hydrogen—per cent.	Oxygen—per cent.	Nitrogen—per cent.	Sulphur—per cent.	Ashes—per cent.	Coke—per cent.
constant .	much .	7· non ad.	5·61	156·5	20	206	10·16	9·95		86·81	4·96	5·22	1·05	·88	1·08	72·19
careful .	much .	3·2	4·5	155·9	40	195	9·8*	9·39 9·91	351·2 526·3	85·58	5·31	4·39	1·26	1·32	2·14	65·13
		25·6	5·4		45	203		7·91	449·2							
constant .	much .	6·6	5·53	158·5	28	203	9·67	9·38		84·92	4·53	6·66	·96	·65	2·28	69·69
much .	do. & soot.	3·5	4·77	157·5	28	199	9·07	8·87	411·66	83·47	6·68	8·17	1·42	·06	·20	62·7
careful .	much .	17·0 non ad.	8·07	159·3	30	202	8·65	8·23	308·	81·81	5·5	2·58	1·28	1·69	7·14	64·61
constant .		14·4	11·89	151·8	33	180	8·71	8·16	300·8	80·26	5·28	2·40	1·16	1·78	9·12	72·31
little .	much .	1·4	4·48	144·6	27	202	8·26	8·04	406·8	80·61	5·26	6·51	1·52	1·85	4·25	
ord. .	much .	2·8	4·40	151·8	17	208	8·05	7·87	457·5	81·85	5·29	7·53	1·64	1·13	2·51	59·20
little .	much .	5·9	4·82	147·7	35	202	8·01	7·82	413·3	80·75	5·04	7·86	1·46	1·04	3·85	
careful .	little .	1·7	4·59	142·8	20	201	7·96	7·77	404·5	82·24	5·42	6·44	1·61	1·35	2·94	35·6
considbl. .	much .	5·0 non ad	5·76	154·5	28	200	8·13	7·71	344·3	79·83	5·11	7·86	1·17	·82	5·21	60·63
little .	considbl. .	2·1	4·47	150·6	23	207	7·83	7·61	402·9	83·26	5·31	2·50	1·72	1·38	5·84	59·42
careful .	considbl. .	7·8 non ad.	4·86	145·5	28	203	7·72	7·57	423·5	80·03	5·08	9·91	·98	·78	3·22	57·18
constant .	much .	9·8	10·45	144·	38	184	7·85	7·48	291·8	83·71	5·30	2·79	1·06	1·21	5·93	61·38
little .	much .	28·3	6·38	145·5	40	202	7·66	7·42	451·1	78·01	4·74	10·31	1·84	1·37	3·73	54·83
much .	little .	5·	3·23	126·6	44	208	7·66	7·3	397·78	81·7	6·17	4·37	1·84	2·85	3·07	59·2
little .	much .	10·1	4·27	133·1	66	155	6·98	6·82	428·4	81·18	5·56	8·03	·72	1·44	3·07	58·22
ord. .	much .	3·7	5·69	143·3	27		7·02	6·79	350·4	82·2	5·10	7·97	1·69	·71	2·33	58·59

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† The duty paid on coals and coke last year was £251,547 11*s.* 7*d.*, of this £175,91 15*s.* 6*d.* was for the port of London, and principally on "sea-borne" or Newcastle coal. The railway dues for the rest of the United Kingdom was only £8363 9*s.* 3*d.*

TABLE No. XVI.—COMPARATIVE COST, MECHANICAL, COMBUS
TWENTY-EIGHT VARIE
LANCA

NAME OF COAL.	COST, per ton, at the		MECHANICAL STRUCTURE.				COMBUSTIBLE		
	Pit.	Nearest Seaport.	Bulk per ton, cubic feet.	Weight per cubic feet—lbs.	Weight of Water in Coals, per cent.	Cohesion of large Coals, per cent.	Light.	Draught required.	Burns.
Ince Hall Companies, Arley	7s.	9s. 6d.	47·05	47·6	1·07	73·5	easily	ord.	cake sligh.
Haydock, Little Delf			49·88	44·9	3·19	66·5	easily	ord.	freely
Balcarres, Arley	6s.		44·35	50·5	1·86	76·	easily	ord.	freely
Blackley, Hurst			46·66	48·0	3·66	65·	ord.	ord.	freely
Ince Hall, Pemberton Yard	Cs. 6d.	8s.6d.to 9s.6d.	46·66	48·0	2·55	75·5	easily	ord.	clear
Haydock, Rushy Park			45·43	49·3	1·89	77·	easily	ord.	freely for a time.
Moss Hall, Pemberton, 4-ft.	6s.		47·35	47·3	3·32	71·5	easily	ord.	clear
Haydock, Higher Florida			45·25	49·5	6·12	74·	easily	ord.	freely for a time
Ince Hall, Pemberton, 4-ft.	6s.	8s.6d.to9s.3d.	43·24	51·8	4·86	74·5	readily	ord.	clear
Blackbrook, Little Delf	6s. to 7s.		43·92	51·	5·58	61·5	easily	ord.	freely
King	8s. 6d.	15s.	44·09	50·8	2·84	78·5	easily	mod. qk.	rapidly
Rushy Park Mine	7s.		47·65	47·	11·66	67·	easily	ord.	clear
Blackbrook, Rushy Park	6s. to 7s.		40·5	55·3	5·90	80·5	easily	ord.	freely
Johnsons and Worthingtons, Rushy Park			44·8	50·	7·15	69·	easily	ord.	clear
Laffak, Rushy Park	7s. 6d.		42·58	52·6	6·24	75·5	easily	ord.	clear
Balcarres, Haigh Yard	6s.	9s.	44·13	50·8	2·69	80·	easily	ord.	steadily
Haydock, Florida Vein			46·66	48·0	6·61	81·5	easily	ord.	freely for a time
Wigan, 4-ft.	5s. 6d. to 6s.	9s. to 9s. 6d.	41·94	53·4	2·69	75·	easily	ord.	rapidly
Ince Hall, Pemberton, 5-ft.	5s. 6d.	8s.	43·24	51·8	4·75	71·5	easily	strong	freely for a time
Cannel (Wigan)	10s. to 12s.	14s. to 18s.	46·37	48·3	1·01	95·	easily	ord.	freely
Ince Hall Co.'s Furnace Vein	5s. 6d.	7s. 6d. to 8s.	45·43	49·3	5·33	71·5	easily	ord.	freely for a time
Balcarres, Lindsay	6s. 8d.		43·83	51·1	6·47	70·	easily	quick	stead. for a time
Caldwell & Thompsons, Rushy Park	5s. 6d. to 7s.	8s. to 9s. 6d.	47·15	47·5	4·97	76·	easily	ord.	clear
Balcarres, 5-ft.	6s. 8d.		45·71	49·	7·12	44·5	easily	ord.	freely
Moss Hall, Pemberton, 5-ft.	5s.		46·37	48·3	3·69	78·5	easily	ord.	freely for a time
Moss Hall Co.'s New Mine	5s.		46·28	48·4	6·76	76·5	easily	ord.	freely for a time
Caldwell & Thompsons, Higher Delf	5s. 6d. to 7s.	8s. to 9s. 6d.	46·28	48·4	0·98	77·	easily	consid.	clear for a time
Johnsons & Worthingtons Sir John	6s.	9s.	43·41	51·6	4·62	82·	diff.	strong	slowly

TIBLE, EVAPORATIVE, COKING, AND CHEMICAL QUALITIES OF

TIES OF LANCASHIRE COALS,

SHIRE.

CHARACTERISTICS.					EVAPORATIVE VALUE.					CHEMICAL COMPOSITION.						
					Steam raised		Water evaporated from 212 by 1 lb. of Coals.									
Attention required.	Smoke.	Clinkers, per ton, Adhesive, lbs.	Residue of Clinkers, Ashes, Cinders, and Soot—per cent.	Calorific Value of 5 grains in Melting Lead—grains.	In Time—mean.	From temp. of Fah.	Power of—lbs.	Realized—lbs.	Rate of, per hour—lbs.	Carbon—per cent.	Hydrogen—per cent.	Oxygen—per cent.	Nitrogen—per cent.	Sulphur—per cent.	Ashes—per cent.	Coke—per cent.
ord. .	much .	10·7 adhes.		162·5	22	204	9·55	9·47	487·29	82·61	5·86	7·44	1·76	·8	1·53	64·
much .	much .	9·6		146·6	13	197	9·26	9·13	532·91	79·71	5·16	10·65	·54	·52	3·42	58·1
ord. .	much .	11·0 adhes.	5·68	147·0	18	205	9·09	8·83	454·1	83·54	5·24	5·87	·98	1·05	3·32	62·89
ord. .	much .	10·8	3·74	147·9	28	192	9·00	8·81	500·8	82·01	5·55	5·28	1·68	1·43	4·05	57·84
ord. .	much .	12·2 non ad.	4·9	150·2	13	205		8·78	461·25	80·78	6·23	7·53	1·36	1·82	2·34	60·6
much .	much .	7·8 adhes.	3·39	149·	12	209	8·91	8·74	461·66	77·65	5·53	10·91	·50	1·73	3·68	59·4
ord. .	much	7·1 adhes.	3·39	142·5	22	204	8·65	8·52	480·	75·53	4·82	7·98	2·05	3·04	6·58	55·7
much .	much .	13·2	3·62	148·6	9	210	8·49	8·39	467·5	77·33	5·56	12·02	1·01	1·03	3·05	51·1
little .	considbl. .	2·1	3·52	144·3	28	193	8·45	8·34	497·39	77·01	3·93	5·52	1·40	1·05	1·09	57·1
careful .	much .	none	3·55	143·4	33	185	8·55	8·29	440·4	82·7	5·55	4·89	1·48	1·07	4·31	58·48
careful .	much .	47·1 adhes.	3·55	136·4	22	203	8·35	8·17	395·41	73·66	5·30	9·06	1·68	1·58	8·72	62·4
ord. .	considbl. .	2·7	3·14	144·9	23	193	8·35	8·08	419·1	77·76	5·23	8·99	1·32	1·01	5·69	56·66
careful .	little .	2·1 adhes.	2·77	151·3	20	198	8·26	8·02	481·2	81·16	5·99	7·20	1·35	1·62	2·68	58·10
ord. .	much .	8·6	3·64	144·5	28	199	8·16	8·01	454·5	79·5	5·15	9·24	1·21	2·71	2·19	57·52
	much .	5·1	3·78	134·0	22	203	8·16	7·98	435·	80·47	5·72	8·33	1·27	1·39	2·82	56·26
ord. .	much .	26·4 adhes.	8·34	140·8	23	207	8·23	7·9	398·3	82·26	5·47	5·64	1·25	1·48	3·90	66·09
much .	much .	9·	3·97	146·3	12	209	8·97	7·83	422·5	77·49	5·50	12·84	1·27	·88	2·02	54·4
ord. .	much .	37·6	7·98	150·1	20	207	8·05	7·77	414·79	78·86	5·29	9·57	·86	1·19	4·23	60·
much .	considbl. .	20·4 adhes.	8·74	143·7	23	208	7·95	7·72	495·2	68·72	4·76	18·63	2·20	1·35	14·34	56·5
careful .	much .	21·1 adhes.	7·84	148·7	20	194	8·06	7·70	381·1	79·23	6·08	7·24	1·18	1·43	4·84	60·33
careful .	much .	25·3 adhes.	7·40	143·	13	211	7·84	7·47	435·21	74·74	5·71	13·52	1·53	·96	4·04	58·4
ord. .	much .	22·3	4·93	131·	25	203	7·58	7·44	431·5	83·9	5·66	5·53	1·40	1·51	2·00	57·84
little .	considbl. .	5·1	2·38	147·1	22	203	7·43	7·34	449·79	76·17	5·46	14·87	1·09	·91	1·50	58·7
ord. .	much .	21·8	4·77	129·8	20		7·35	7·21	489·5	74·21	5·03	8·69	·77	2·09	9·21	55·90
much .	much .	31·9 adhes.	6·35	137·4	20	202	7·29	7·18	417·18	76·16	5·85	10·13	1·29	1·05	6·02	56·1
		34·2 adhes.	5·86	135·1	23	204	7·10	7·04	422·08	77·50	4·84	12·16	·98	1·86	3·16	57·7
much .	much .	38·6 adhes.	5·85	141·8	40	188	6·94	6·85	484·28	75·40	4·83	19·98	1·41	2·43	5·95	54·2
much .		34·4	9·42	119·	22	209	6·62	6·82	362·7	72·86	4·98	8·15	1·07	1·54	11·4	56·15

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TABLE No. XVII.—COMPARATIVE COST, MECHANICAL, COMBUSTIBLE, VARIETIES OF DERBYSHIRE, EIGHT OF SCOTCH COALS, SIX

NAME OF COAL.	COST, per ton, at the		MECHANICAL STRUCTURE.				COMBUSTIBLE		
	Pit.	Nearest Seaport.	Bulk per ton, cubic feet.	Weight per cubic feet—lbs.	Weight of Water in Coals, per cent.	Cohesion of large Coals, per cent.	Light.	Draught required.	Burns.
									DERBY
Earl Fitzwilliam's Elsecar		5s. 9d.	47·45	47·2	4·83	77·	easily	mod.	freely
Hoyland and Co.'s Elsecar		5s. 9d.	46·47	48·2	3·72	82·5	easily	mod. qk.	freely
Earl Fitzwilliam's Park Gate			47·65	47·	3·08	78·	easily	mod. qk.	freely
Butterly Co.'s Portland		6s. 9d.	47·55	47·1	7·36	89·	easily	mod. qk.	free
Butterly Co.'s Longley		6s.	46·86	47·8	3·55	84·5	easily		free
Staveley		9s.	44·88	49·9	8·54	88·5	easily	ord.	freely
Loscoe, Soft	5s. to 7s.		50·0	44·8	9·76	62·	readily	ord.	freely for a time
Loscoe, Hard	5s. to 7s.		48·8	45·9		86·	readily	ord.	freely for a time
									SCOT
Elgin Wallsend			41·02	54·6	2·49	64·	easily	ord.	freely
Wellewood		8s. 6d.	42·58	52·6	2·77	80·	easily	ord.	freely
Dalkeith Coronation			43·36	51·66	5·3	88·2	easily	ord.	freely
Kilmarnock Shevington		6s.	50·11	44·7	7·76	63·5	easily	ord.	freely
Fordel Splint		9s.	40·72	55·0	8·4	63·	easily	ord.	stg. flame
Grangemouth		9s.	40·13	54·25	6·42	69·7	easily	ord.	mod.
Eglinton		7s. 4d.	43·07	32·0	10·02	79·5	easily	ord.	rapid
Dalkeith Jewel			44·93	49·8	9·7	85·7	easily	ord.	freely
									VARI
Slievardagh Irish Anthracite	20s. to 25s.		35·66	62·8	4·93	74·	difficultly	strong	clear
Coleshill Co.'s Bagilt Main		7s.	45·16	49·6	5·50	79·	easily	ord.	freely
Ewloe			44·44	50·4	6·83	84·	easily	quick	clear
Ibstock	7s. 6d.		47·35	47·3	1·12	62·	easily	quick	clear
Forest of Dean (Lydney)		10s. to 11s.	41·14	54·44	2·78	55·	easily	mod.	smoky
Conception Bay (Chili)					13·52		easily	ord.	freely
									PATENT
Warlich's Patent Fuel			32·44	69·05	·92		slowly	ord.	mod.
Livingstone's Steam Fuel			34·14	65·6	1·39		difficultly	ord.	slowly
Lyon's Patent Fuel			36·66	61·1	1·91				mod.
Wylam's Patent Fuel			34·41	65·08	1·38		readily	quick	freely
Bell's Patent Fuel			34·30	63·3	·9		slowly	ord.	d.
Holland and Green's			34·56	64·8	2·18		easily		freely for a time

V.

EVAPORATIVE, COKING, AND CHEMICAL PROPERTIES OF EIGHT OTHER VARIETIES, AND SIX VARIETIES OF PATENT FUEL.

CHARACTERISTICS.					EVAPORATIVE VALUE.					CHEMICAL COMPOSITION.						
					Steam raised		Water evaporated from 212° by 1 lb. of Coals.									
Attention required.	Smoke.	Clinkers, per ton, Adhesive, lbs.	Residue of Clinkers, Ashes, Cinders, and Soot—per cent.	Calorific Value of 5 grains in Melting Lead—grains.	In Time—mean.	From temp. of Fah.	Power of—lbs.	Realized—lbs.	Rate of, per hour—lbs.	Carbon—per cent.	Hydrogen—per cent.	Oxygen—per cent.	Nitrogen—per cent.	Sulphur—per cent.	Ashes—per cent.	Coke—per cent.
SHIRE.																
much		6·6	5·95	150·5	23	198	8·78	8·52	412·7	81·93	4·85	8·58	1·27	·91	2·46	61·6
much	much	1·7	7·9	148·6	23	197	8·43	8·07	372·91	80·05	4·93	8·99	1·24	1·06	3·73	62·5
much		none.	7·60	150·6	22	199	8·24	7·92	393·75	80·07	4·92	9·95	2·15	1·11	1·80	61·7
careful	much	10·3 non ad.	4·39	155·2	22	199	8·04	7·92	487·08	80·41	4·65	11·26	1·59	·86	1·23	60·9
careful	much	10·0	6·48	150·	15	209	7·98	7·8	398·69	77·97	5·58	9·86	·80	1·14	4·65	54·9
ord.	much	12·6	4·78	140·4	22	207	7·40	7·26	466·2	79·85	4·84	10·96	1·23	·72	2·40	57·8
great	much	8·4 adhes.	3·36	140·2	22	208	7·99	6·83	490·06	77·49	4·861	2·41	1·64	1·30	2·03	52·8
great	much	8·5 adhes.	4·64	147·9	18	208		6·32	431·42							
CH.																
little	considbl.	14·5	4·73	145·3	28	203	8·67	8·46	435·77	76·09	5·22	5·05	1·41	1·53	10·70	58·45
little	much	28·5	4·50	142·4	35	181	8·39	8·24	438·5	81·36	6·28	6·37	1·53	1·57	2·89	59·15
little	little	62·2	5·9	122·8	30	180	7·86	7·71	370·08	76·94	5·2	14·37	trace	·38	3·10	53·5
careful	much	6·4	3·42	151·6	17	202	7·82	7·66	470·83	79·82	5·82	11·31	·94	·86	1·25	49·3
little	considbl.	3·	2·86	145·0	40	176	7·69	7·56	464·98	79·58	5·5	8·33	1·13	1·46	4·0	52·03
ord.	little	16·4	5·26	142·4	28	208	7·91	7·40	380·4	79·85	5·28	8·58	1·35	1·42	3·52	56·6
ord.	much	82· non ad.	4·03	121·6	33	186	7·48	7·37	406·2	80·08	6·5	8·05	1·55	1·38	2·44	54·94
little	little	59·5	3·92	132·1	40	193	7·1	7·08	355·18	74·55	5·14	15·51	·10	·33	4·37	49·8
OUS.																
careful	none	17·9	7·25	150·5	110	150	10·49	9·85	473·18	80·03	2·3	in ash.	·23	·76	10·8	90·1
ord.	mod.	5·7	3·92	152·	28	197	8·5	8·33	461·25	88·48	5·62	·86	2·02	1·36	1·62	55·8
careful	mod.	4·4	4·72	135·6	17	208	7·16	7·02	363·95	80·97	4·96	8·20	1·1	1·4	3·37	54·5
careful	little	14·1 non ad.	4·10	125·5	20	206	7·02	6·91	454·16	74·79	4·83	11·88	·88	1·45	5·99	50·8
ord.	much	2·45	4·06	129·7	20	218	8·98	8·52	487·19							
careful	much	44·5 ad.	8·48	128·1	30	208	5·96	5·72	425·							
FUELS.																
careful	little	29·6	6·79	157·5	30	203	10·60	10·36	457·84	90·02	5·56	in ash.	trace	1·62	2·91	85·1
much	little	28·2	10·95	162·7	33	194	10·57	10·03	483·95	86·07	4·13	2·03	1·80	1·45	4·45	
much	much	38·7	6·06	156·9	38	189	9·77	9·58	409·1	86·36	4·56	2·07	1·06	1·29	4·66	
ord.	mod.	59·5	7·27	144·1	35	199	9·74	8·92	418·89	79·91	5·69	6·63	1·68	1·25	4·84	65·8
great	considbl.	76·1	6·7	142·6	37	201	8·65	8·53	649·11	87·88	5·22	0·42	·81	·71	4·96	71·7
much	considbl.	87·6	12·55	118·4	22	204	7·86	7·59	470·0	70·14	4·65		1·15		13·73	

Table No. XVIII.

SUMMARY OF THE MEAN AVERAGES OF THE COALS FROM DIFFERENT LOCALITIES.

	MECHANICAL STRUCTURE.			EVAPORATION OF WATER			CHEMICAL COMPOSITION.						
	Bulk of 1 ton	Weight of 1 cub. foot.	Cohesion per cwt. of large coals.	By 1 lb. of coals.	Per hour.	Sulphur per cent.	Carbon per cent.	Hydrogen per cent.	Oxygen per cent.	Nitrogen per cent.	Sulphur per cent.	Ashes per cent.	Coke per cent.
Welsh, 37 samples .	cub. ft. 42·71	lbs. 53·1	60·9	lbs. 9·05	lbs. 448·2	1·42	*83·78	4·79	4·15	0·98	1·43	4·91	72·6
Newcastle, 17 ditto .	45·3	49·8	67·5	8·37	411·1	0·94	82·12	5·31	5·69	1·35	1·24	3·77	60·67
Lancashire, 28 ditto .	45·15	49·7	73·5	7·94	447·6	1·42	77·0	5·32	9·53	1·930	1·44	4·88	60·22
Scotland, 8 ditto .	49·99	50·0	73·4	7·7	431·4	1·45	78·53	6·61	9·69	1·0	1·11	4·03	54·22
Derbyshire, 8 ditto .	47·45	47·2	80·9	7·58	432·7	1·01	†79·68	4·94	10·28	1·41	1·01	2·65	59·22

* Mean of 36 samples. † Of seven experiments.

Table No. XIX.

CHEMICAL COMPOSITION OF VARIOUS FOREIGN AND COLONIAL COALS.

VAN DIEMEN'S LAND.

Name.	Water.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.
South Cape	3·33	63·4	2·89	1·01	1·27	·98	30·45
Mnt. Nicholas Break o'Day	7·24	57·37	3·91	9·10	1·15	·90	27·55
Tingal	4·86	57·21	3·38	7·8	1·2	1·32	29·09
Jerusalem	3·06	68·18	3·99	5·89	1·62	1·12	19·20
Douglas River, East Coast	4·87	70·44	4·20	9·27	1·11	·70	14·38
Tasman's Peninsula	4·40	65·54	3·36	1·75	1·91	1·03	26·41
Schoten Island	2·17	64·01	3·55	3·38	·94	·85	27·17
Whale's Head, South Cape	1·72	65·86	3·18	7·20	1·12	1·14	21·50
Adventure Bay	3·81	80·22	3·05	4·8	1·36	1·9	8·67
VARIOUS.							
Sydney, New South Wales	3·25	82·39	5·32	8·32	1·23	·70	2·04
Borneo, Labuan	..	64·52	4·74	20·75	·80	1·45	7·74
„ 3 ft. Seam	..	54·31	5·03	24·22	·98	1·14	14·32
„ 11 ft. Seam	..	70·33	5·41	19·19	·67	1·17	3·23
Formosa Island	..	78·26	5·70	10·95	1·64	·49	3·96
Vancouver's Island	7·21	66·93	5·32	8·70	1·02	2·20	15·83
Lignite, Trinidad	2·62	65·20	4·25	21·69	·33	·69	6·84
CHILIAN.							
Conception Bay	..	70·55	5·76	13·24	0·95	1·98	7·52
Port Famine	14·63	64·18	5·33	22·75	0·50	1·03	6·21
Chirique	9·11	38·98	4·01	13·38	·58	6·14	36·91
Laredo Bay	16·03	58·67	5·52	17·33	·71	1·14	16·63
Talcahnano Bay	12·43	70·71	6·44	13·95	1·08	·94	6·92
Colcurra Bay	5·89	78·30	5·50	8·37	1·09	1·06	5·68
PATAGONIAN.							
Sandy Bay No. 1	22·68	62·25	5·05	17·54	·63	1·13	13·14
„ No. 2	22·26	59·63	5·68	17·45	·64	·96	15·64
Juan Fernandez	6·06						

TABLE No. XX.

CHEMICAL ANALYSIS OF FORTY-TWO VARIETIES OF AMERICAN COALS.

ANTHRACITE.				BITUMINOUS.			
Name.	Carbon, per cent.	Gases, per cent.	Ashes, per cent.	Name.	Coke.	Gases.	Ashes.
Nesquehoning	86·6	6·4	7·	Wilkesbare Ward. Carbondale	90·23	7·07	2·70
Le High Summit	88·5	7·5	4·	Hopewell Furnace	88·2	11·2	4·
„ hardest	87·7	6·6	5·7	Lick Run	79·28	20·72	13·07
Tamaqua D Vein	92·07	5·03	2·9	Queen's Run	78·28	21·2	2·07
„ E Vein	89·2	4·54	6·26	Moshanna Creek	70·50	29·5	6·1
„ R Vein	87·45	7·55	5·10	Steed's Mine	79·6	20·4	11·20
Fuscurora	88·2	7·5	4·3	Leech's Mine	79·68	20·32	11·75
Pottesville Schuyl. Comp. Schene-with	94·1	1·4	4·5	Ralstan Lyconing Company	79·50	20·5	5·
				Karthaus Upper Seam	87·	13·	8·80
Neeley's Tunnel	89·2	5·4	5·4	„ Lower Seam	75·2	24·8	4·70
Sharp Mountain P.G.	80·57	7·15	3·28	Reed's Six-Feet Vein Curwinsville	73·	27·	5·30
Black Spring Gap	82·47	9·53	8·00	Bear Creek	68·	32·	5·20
„ Lea Vein	85·84	8·96	5·20	Warner's Caledonia Three Feet	61·8	38·2	7·20
„ Grey Vein	81·02	9·78	9·20	„ „ Five Feet	63·	37·	8·5
Gold Mine Gap Pea. Vein	82·15	10·95	6·90	Blairsville	69·	31·	4·
„ Heister Vein	81·47	10·63	8·1	Sandy Ridge	56·8	43·2	7·
Yellow Spring Gap	79·55	10·95	9·50	Venango Company's Cannel	47·22	52·78	17·68
Ruttling Vein	74·55	15·75	11·70	Greersberg	64·0	36·0	33·88
Big Flats	76·94	13·06	8·0	Coneant Lake	61·25	38·75	1·8
Lyken's Valley	88·25	8·85	2·90	Greenville	59·5	40·5	1·7
Shamohin	89·90	6·10	4·	Orangeville	56·25	43·75	2·8
Wilkesbare Ward.	88·9	7·68	3·42	Snowshoe	78·8	21·2	2·07

NOTE.—All the varieties contain more or less of sulphur. In the anthracite running from ·48 to ·91 per cent. of the ashes, and in the bituminous from 2·6 to 2·7 per cent. The general characteristics of each kind are, for anthracite, economy of space, freedom from smoke, and cleanliness; for bituminous, free combustion, smokiness, and less durability than the anthracite.

The ratio of carbon in coals, it is thus seen, varies considerably; so also does the quantity of hydrogen. Generally, bituminous coals yield less carbon than anthracite coals, but more hydrogen. Bitumen renders coals easily ignited and smoky, whilst it gives them that caking quality so much appreciated for domestic use in London, by melting the coals together, thereby closing the top of the fire, and, by preventing the heat being so rapidly carried up the chimney, causes it to radiate more into the apartment. It also at the same time tends to prevent light ashes flying about, an evil so much complained of with less bituminous coals.

Anthracite contains more carbon than bituminous coals, is more clean, by burning nearly free from smoke, and is now variously used.

The following is the average range of composition in 100 pounds of each fuel:—

BITUMINOUS COALS.

Carbon	53 to 88 lbs.	in every 100 lbs. of coals.
Volatile gases (nitrogen, oxygen, and hydrogen) .	44 to 10·5	,,
Ashes	3 to 1·5	,,
Total	100 or 100	

ANTHRACITE.

Carbon	75 to 94 lbs.	in every 100 lbs. of coals.
Volatile gases (nitrogen, oxygen, and hydrogen) .	14 to 1·5	,,
Ashes.	11 to 4·5	,,
Total	100 or 100	

The coal-tables supply a detailed analysis of each of the numerous varieties therein named.

In making coal-gas for illumination, the quantity of carburetted hydrogen evolved varies from about 5,000 to 11,800 cubic feet per ton of coals, and is thus estimated—

Scotch cannel	11,800	cubic feet of gas
Lancashire cannel	11,600	„
Newcastle	9,600	„
Staffordshire	6,400	„
Wallsend	10,300	„
Templemain	6,200	„
Tenby	4,200	„

Besides lighting purposes, attention has been drawn to the heating power of gas in domestic economy. Mr. Defries raised the temperature of 45 gallons of water from 50° to 100° Fahr. by 30 cubic feet of gas, at a cost of 1½*d.* Mr. Evans estimates the heating power of 1 cubic foot of Newcastle coal gas as equal to boil off into steam 22 times its own weight of water, and practically boiled off from 12 to 13·6 times its own weight as below:—

Gas burnt cubic ft.	WEIGHT OF GAS.		WATER BOILED.		Heating power.
	Grs.	Spe. grav.	lbs.	Ratio to gas.	Ratio.
1	206	·416	—	—	22
1	205	·413	·4	13·6	—
1	290	·564	·5	12·0	—
1	360	·700	·7	13·6	—

Evaporative Value of the Hydrogen in Coals.

It has been usual, as previously stated, to regard the heat given out by the combustion of hydrogen as little more than compensating for its production, and that by the quantity of carbon in any fuel its evaporative value was indicated.

A close examination of the experiment at the Par Consols Mine appears to indicate that the hydrogen does exercise a beneficial result on the evaporative powers of the fuel. The quantity of water evaporated was 11·428 lbs. by 1 lb. of coals, and their composition was 84·19 of carbon, 4·19 of hydrogen, 86 of oxygen, 8 of nitrogen, 1·9 of sulphur, and 8·06 of ashes. The water being at 212° temperature required only 965·7° of heat to convert it into steam. Taking Dulong's values of 13268° of heat for carbon, and 62470° of heat for hydrogen, in this instance, we can readily compare the theoretical with the practical effect.

Theoretically we have,

$$\text{Carbon} = \frac{84{\cdot}19 \times 13268}{100 \text{ lbs.} \times 965{\cdot}7} = 11{\cdot}567 \text{ lbs. of water,}$$

$$\text{and for hydrogen} = \frac{4{\cdot}19 \times 62470}{100 \text{ lbs.} \times 965{\cdot}7} = \underline{2{\cdot}71} \text{ lbs. of water,}$$

total theoretical value of 1 lb. of coals = 14·267 or

$$\begin{array}{rcr} \text{together, carbon} = 84{\cdot}19 \times 13268 & = & 1117032{\cdot}92 \\ \text{hydrogen} = 4{\cdot}19 \times 62470 & = & 261749{\cdot}30 \\ \hline & & 1378782{\cdot}22 \end{array}$$

as the units of heat in 100 lbs. of coals, which being divided by the evaporative heat of 965·7° × 100 lbs. of coals = 14·277 lbs. of water, capable of being evaporated by 1 lb. of these coals.

Practically, 1 lb. of coals evaporated 11·428 lbs. of water from 212°, or only ·139 lb. less than the theoretical value of carbon. But this 11·428 lbs. was not all the heat actually obtained from the fuel; for it is stated that, by an arrangement of water-pipes in the flues, the feed-water was heated to about 212° by the heat absorbed from the passing gases on their way to the chimney, where their temperature was still 300°. Taking the ordinary temperature of water as 52°, it requires to absorb 160° to raise it to 212°; hence the actual evaporation of $\frac{10{\cdot}204 \times 160}{965{\cdot}7} = 1{\cdot}690$ lb. of additional evaporative heat from the coals, making 11·894 lbs. as the total heat absorbed, or ·327 lb. more than was possible by the carbon, and 2·37 less than the total theoretic value of 1 lb. of coals. Without considering the 300° of heat still left to escape up the chimney, the beneficial effect of the hydrogen in the evaporative results is quite evident.

The Mynydd Newydd coals having a similar large proportion of hydrogen (4·28 per cent.), it will be seen by the Table that they have a higher practical value than several others possessing more carbon but less hydrogen.

Taking as another example the Aberaman Merthyr coal, containing 90·94 per cent. of carbon and 4·28 of hydrogen, possessing the highest evaporative value in these tables, or 10·75 lbs. under the experimental boiler,

For the Cornish boiler the evaporation would be—

10·75 × 1·1995 = 12·894 lbs., and as before,
Carbon .. 90·94 × 13268 = 1206591·92, or 12·494 lbs.
Hydrogen .. 4·28 × 62470 = 267371·60, or 2·769 lbs.

$$\frac{1473963 \cdot 52}{100 \times 965 \cdot 7} = 15 \cdot 263 \text{ lbs.}$$ as the theoretic value of 1 lb. of these coals.

Taking the absorption of carried heat by the feed-water to be, as before, equal to 160° for the quantity evaporated, we have $\frac{10 \cdot 75 \times 160}{965 \cdot 7} = 1 \cdot 781$ lbs. as its value, and 10·75 + 1·781 = 12·531 lbs., or ·037 more effect from an inferior boiler than due to the carbon.

Heating of the Feed-water.

It is not unusual to find a very high value placed upon this practice, by those who have not fully investigated the matter. The last two examples show that in the one case it added 1·69, and in the second case 1·78 lbs., to the evaporative value of the fuel, when the water was heated to 212°. The mistake arises from supposing that only 212° of heat are required to evaporate steam of atmospheric pressure, whilst by Regnault's careful experiments it requires 965·7° + 212 = 1177·7°. From this is to be deducted the initial temperature of the water, which if taken at 52° leaves 1125·7°

to be imparted in order to convert that water into steam. Hence,

$$\frac{1125{\cdot}7}{212-52} = 7{\cdot}04, \text{ or } 14{\cdot}19 \text{ per cent.}$$

as the utmost gain. If less than the boiling temperature is attained by such heating, then the gain would be proportionally decreased, as shown in the following Table :—

TABLE No. XXI.

Ratio of the Heat applied to Feed-water to the total Heat of Steam of Atmospheric Pressure, or 1177·7° less the Initial Heat of the Water, or say 52° Temperature = 1125·70.

Water heated from 52° to Fah.	Increase in deg. Fah.	Increase per cent. of the heat of Steam.
62	10	·887
72	20	1·77
82	30	2·66
92	40	3·54
102	50	4·43
112	60	5·32
122	70	6·20
132	80	7·09
142	90	7·98
152	100	8·87
162	110	9·75
172	120	10·64
182	130	11·53
192	140	12·41
202	150	13·30
212	160	14·19

CHAPTER VII.

COKE.

In the Report on Coals for the Navy, Sir H. De la Beche and Dr. Lyon Playfair state, "The whole system of manufacturing coke is at present imperfect;" and condemn the management which allows some of the valuable products from the ovens to be lost, stating, as one instance of such loss, that for every 100 tons of coke made, about 6 tons of sulphate of ammonia, worth about £13 per ton., could be collected and sold. To stimulate such economy they give the following ratios of ammoniacal products in the respective coals named :—

TABLE No. XXII.

Ammoniacal Products in Coals.

Name or Locality of Coal,	Amount of Ammonia corresponding to the Nitrogen contained in Coal.	Amount of Sulphate of Ammonia corresponding to the Nitrogen contained in Coal.
Graigola	0·497	1·932
Anthracite {Jones, Aubrey, and Co.}	0·225	0·990
Oldcastle Fiery Vein .	1·590	6·175
Ward's Fiery Vein . .	1·238	4·808
Binea	1·586	6·741
Llangenock . . .	1·299	5·044
Pentripoth . . .	0·218	0·848
Pentrefellin . . .	Trace	...
Powell's Duffryn . .	1·76	6·835

Name or Locality of Coal.	Amount of Ammonia corresponding to the Nitrogen contained in Coal.	Amount of Sulphate of Ammonia corresponding to the Nitrogen contained in Coal.
Mynydd Newydd	1·808	7·340
Three-quarter Rock Vein	1·299	5·044
Cwm Frood Rock Vein	1·347	5·232
Cwm Nanty Gros	1·919	7·448
Resolven	1·675	6·505
Pontypool	1·639	6·364
Bedwas	1·748	6·788
Ebbw Vale	2·622	10·182
Porthmawr Rock Vein	1·554	6·033
Coleshill	1·785	6·930
Dalkeith Jewel Seam	1·214	0·471
Dalkeith Coronation	Trace	...
Wallsend Elgin	1·712	6·647
Fordel Splint	1·372	5·327
Grangemouth	1·639	6·364
Broomhill	2·234	8·674
Park End, Lydney	1·477	9·617
Slievardagh (Irish)	0·279	1·084
Formosa Island	0·777	3·017
Borneo (Labuan kind)	0·977	3·771
,, 3 feet seam	1·132	4·620
,, 11 ,,	0·813	3·158
Wylam's Patent Fuel	2·040	7·920
Warlich's ,,	Trace	...
Bell's ,,	0·983	3·818

Besides these products there are also much heat and much hydrogen gas evolved during coking, which are seldom turned to any profitable account. Several iron works employ the escaping gases from their furnaces with economical results. In cooling coke in the ovens there is a considerable quantity of pure hydrogen produced from the decomposition of the water by the intense heat of the oven. It is at least worth a trial to determine the commercial value of collecting such products of the coke furnace.

✓ The best process of manufacturing coke is an open question, some engineers preferring *hard*, others *soft* burnt coke, but the preponderance of numbers is in favour of the hard coke. Our observations tend to a different result. The comparative term *hard* is understood to apply to coke from which all volatile matters have been expelled, and the term *soft* to refer to coke in which a portion of these gases still remain. The distinction applies equally to different portions of the same vertical piece of coke in the oven. The upper part may be comparatively hard, and further heat would have little to expel from it, whilst the lower part near the bed of the oven may be *softer*, and would evolve a gaseous flame, by being exposed to further heat.

* This darker or comparatively softer part we regard as the most economical generator of steam in locomotive furnaces, arising from its retaining a portion of the original gases in the coals. That hydrogen gas is more valuable in generating steam than has usually been estimated, is shown from practical examples with coals at the Par Consols mine, already noticed, where they *water* their open-burning coals to give *intensity* of heat in the furnace. When coke was the staple fuel for locomotives, many of the best locomotive drivers used to *water* their coke to make it "*last longer;*" the water being introduced in a finely divided state into an intensely hot fire, which decomposed it into its equivalent of hydrogen and oxygen, and thus aided the evaporative power of the fuel. From the coking property of some coals, water could not be beneficially used with them for steaming, since it would increase the tendency to coke, and retard the generation of steam by presenting to the boiler a fire-surface comparatively cold to that presented by the glowing intensity of open-burning coals. This difference may be observed in a common house fire, when the poker is required to break the surface to obtain greater heat, whilst with other coals no such coking occurs, nor is "pokering" the fire required.

The blacksmith's forge is an every-day instance of wetted coals producing a very superior fire to coals in their ordinary state where intensity of heat is required in the centre of the fire, and not to radiate externally against a boiler or other object. Whatever evaporative benefit may be derived from such introduction of water arises, it is evident, from the gases evolved.

It is usually held that the portion of hygroscopic water in coals, varying from 1 to 2 per cent., and the water absorbed by coke, varying from 1 to 7 per cent., cause not only a loss of weight, but also require part of the remaining fuel to evaporate such water. That it would be injudicious to purchase wet fuel—also that such wetted fuel might sensibly retard the lighting of a fire—is evident; but it may well be that if a small percentage of water can be converted into hydrogen and oxygen, it will be more valuable than an equal weight of either coals or coke.

Unless urged by a strong draught, nearly all the forms of pure carbon burn badly. The diamond long resisted the action of heat until Lavoisier succeeded in fusing it, and showed it to be pure carbon. Coke requires a strong draught to promote its combustion. Lampblack in certain states ignites spontaneously in casks, but even on being exposed to the air it presents only the appearance of a number of minute sparks, with little heat and no flame. The least admission of air to spontaneously ignited coals, on the contrary, produces immediate conflagration. Now, if the process of coking could be so far perfected as to retain a considerable portion of these combustible elements of coals, and only expel the smoky portion, the economy would be obvious.

The gauge contest, about the year 1848, which so rapidly promoted locomotion, afforded some information on the economy of hard and soft coke. The Newcastle or Durham coke principally used on the northern railways bore a high name for its evaporative power and durability, whilst the Welsh coke used on the Great Western Railway had only a local character inferior to the northern coke, and a claim was made for an equivalent allowance for this supposed difference. After these trials were over the question was practically tested in the broad-gauge engines, ending, contrary to anticipation, in favour of the softer Welsh coke, as regarded *time* and *load*, with draughts suited to each variety. It was found that the blast-pipe used for Welsh coke was too large, and the draught too little for the Newcastle coke, and the engines failed to keep time until the blast-pipe was made less. This of course increased the draught and promoted the combustion of the coke, but it introduced the evil of increased resisting pressure against the piston, leaving a balance in favour of the Welsh coke for equal loads at equal velocities by equal quantities of coke. Of the Welsh coke, the softer burnt was likewise found the best, and produced the best results in a locomotive boiler. An annoying instance of this occurred when the power of a particular engine was to be tried. The more beautiful-looking upper parts of the coke were selected to fill the tender, and the trial proved a failure for want of steam. The rejected portion of the coke, supplied to an engine for ordinary duty, produced a contrary result.

In Lancashire, again, a contrary opinion was arrived at, and the inability of coke to resist the action of a hard-coke blast was assigned as a reason for its inferiority to harder coke, although it is clear that if this coke could have generated even less steam with a larger blast-pipe than the hard coke with a small one, the effective power of the engine to draw a load might still have been equal. For every pound of resisting pressure taken away gives more than a corresponding advantage to the acting pressure, since there is less steam to escape for an equal amount of tractive power given out. Coke, like coals, varies considerably in its heating power, requiring the draught and process of combustion to be carefully attended to for each quality, so as to evolve the best results. Mr. Woods states, that, as compared to the Hutton and Worsley cokes taken as 100, the practical values of six other varieties not named were, respectively, 76·3, 80·3, 81·7, 89, 90, 90·1, as tried, it would appear, under similar circumstances, which, however, might not be a fair trial for the peculiarities of each coke, since the tenderness above referred to was stated as one cause of inferiority.

Coke-ovens.

Like charcoal, coke was formerly made in heaps roughly covered from the air, but furnaces or ovens are now employed for that purpose. These ovens are of various forms, but it is not so much the form as the proper admission of air to the coking coals which is of importance. With a well-regulated supply of air there is not found to be any marked superiority in the most costly ovens over the cheaply constructed circular oven of which Figs. 82, 83, 84, show an elevation, section, and plan. They usually hold about five or six tons of coals, and the air is admitted by the doorway at *a a a*, which is finally closed as required and luted with clay. When the process of coking is completed the brick-built door is taken down and water injected into the oven to cool down the

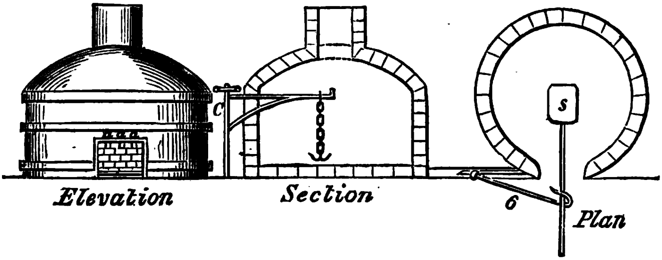


Fig. 82. Fig. 83. Fig. 84.
Circular Coke-Oven.

coke. On this being done, the coke is removed by the crane C, and the large iron shovel *s*, from the oven, which is then ready to be filled again. A number of these ovens may be erected in one cluster, and connected with a central chimney.

Church's circular ovens were on the same general plan, with a series of air-passages below the coke-bed, but not in contact with the coke. When the coking process was complete these passages were opened, to admit a current of cold air to aid in cooling down the hot coke, which was effected by carefully excluding all air from the oven without the use of water. Coke so made was, therefore, perfectly dry and free from hygrometric water (until it absorbed it from the atmosphere), and enjoyed considerable repute for its steaming power.

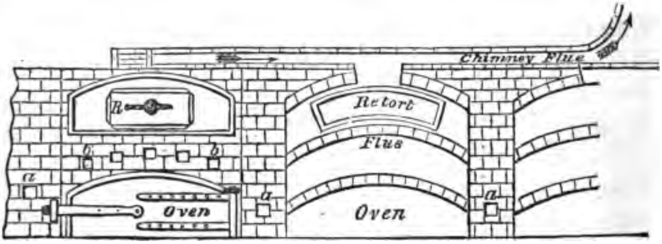


Fig. 85.—Cox's Oven.—Elevation Section.

The plan of cooling with water is now generally preferred, and when done in the oven there is a better return of large coke than when drawn out hot and cooled outside the oven.

Cox's oven is arranged to make both coke and gas at one time, as seen in Fig. 85.

In this oven the air is admitted by the side passages *a a*, passing along the brickwork and opening into the back of the oven, as seen in Fig. 86. By this arrangement the air is heated before it comes near the coking coal, and passes by the flue to the chimney, as seen by the arrows. When gas is required a retort R is placed in the upper arch, which is acted upon by the escaping heat of the oven. For coke alone the upper arches might be dispensed with, and the chimney placed at the front instead of the back, which would reduce the cost of erection without impairing the quality of the coke. *b b* are eye-holes for observing the process of coking by the escaping products of combustion, and also for admitting air to promote the draught, as may be required. The coke is drawn out hot on the "cradle," Figs. 87, 88, which show the plan and edge view of this implement. It is placed on the floor of the oven, as seen at C, in Fig. 86, and the coals put in the oven afterwards. When the coking is completed the door is opened, and a strong chain from a crab is attached to the hook of the cradle, and by the exertion of two or three men working the crab the whole mass is drawn at once from the oven hot, and cooled with water afterwards. The coke being more friable when hot than when cold, there is rather more small coke by this plan than by cooling in the oven.

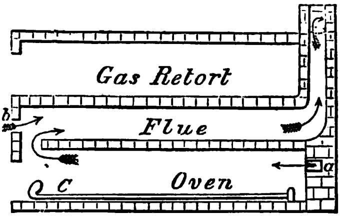
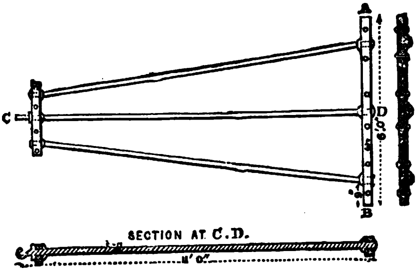


Fig. 86.—Longitudinal Section.



Figs. 87 and 88.

Amongst the most recently constructed coke-ovens are those of the Bristol and Exeter Railway at Bridgewater.

In them is embraced some improvements, with modifications of both Church's and Cox's ovens. Church's cooling air-passages are made to come in contact with the coke, to promote equal ignition, and the side air-passages have frequent openings into the oven, whilst the upper passages further regulate the admission of air, as fully illustrated in the following drawings from the "Aide-Mémoire of Military Sciences."

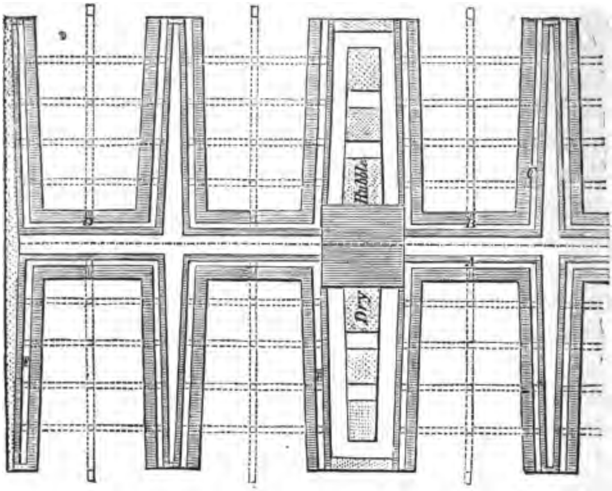


Fig. 89.—Coke-Oven. Ground or Floor Plan.

Fig. 89 is a ground plan of eight coke ovens, communicating with a central chimney, showing the lowest side air-passages leading from the front, and by the transverse dotted passages underneath the coals to promote equal ignition of the whole mass at once. When this is done these passages are closed for that occasion.

Fig. 90 is a plan at the upper air-passages for regulating the supply to the burning fuel. The side openings introduce the air so as to distribute it as equally as possible above the burning mass. The spaces parallel with the chimney between the ovens are filled up with dry rubble, as shown in both plans.

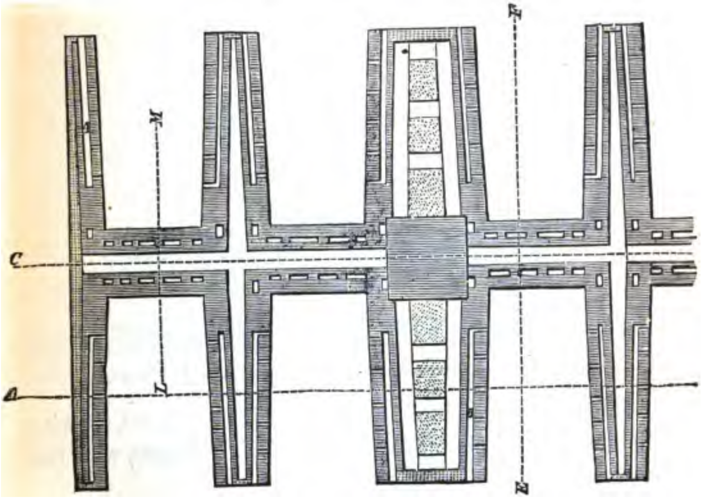


Fig. 90.—Coke-Oven. Plan at Air Passage.

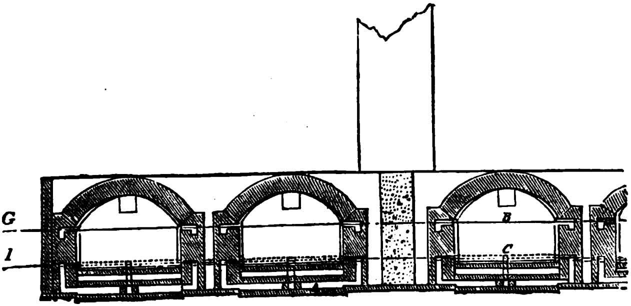


Fig. 91.—Coke-Oven. Transverse Section at A B, Fig. 90.

Fig. 91 is a section, at A B, of Fig. 90, showing the vertical construction of the ovens, air-passages, side openings, lowest air-passages, and central openings, leading into the flue which connects them with the chimney.

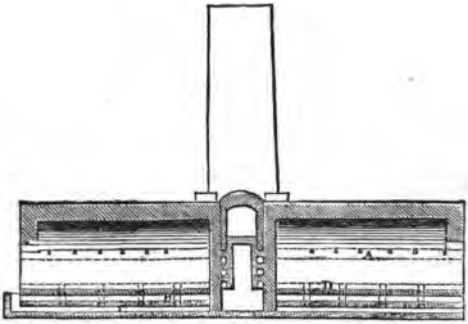


Fig. 92.—Coke-Oven. Longitudinal Section at E F, Fig. 90.

Fig. 92 is a section of two ovens at E F, Fig. 90, showing the longitudinal plan of the ovens and air-passages, with the manner of their junction at the back.

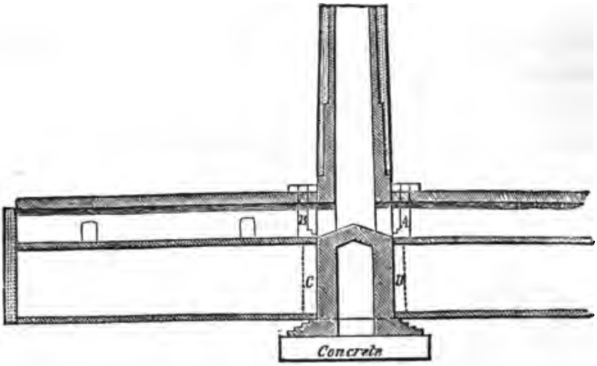


Fig. 93.—Coke-Oven. Longitudinal Section of Oven and Chimney Flues.

Fig. 93 is a longitudinal section of the oven and chimney-flue, with the dampers A, B.

Fig. 94 is a section between the ovens at C D, showing their connection with the chimney.

Fig. 95 is a front elevation of two ovens, showing the external air-orifices A, B, with the form of the cast-iron doors and fittings.

The process of making coke with all these ovens is to fill them with their respective quantities of coals in such rotation as to produce a daily supply of coke. When the coke is cooled in the oven, the coals require to be lighted; but when the coke is drawn out hot, the coals then put in ignite readily by the heat of the oven. The door is then lined inside with fire-bricks, and closed and luted with fire-clay, to make it air-tight. Sometimes no door is used, and the opening is built up with fire-bricks, leaving regulating air-passages to be closed as the coking progresses. The duration of the process is from 48 to 96 hours, but is a good deal dependent on the composition of the coals, the state of the atmosphere, and the class of oven employed. When coals contain little or scarcely any sulphur, the process is slow.

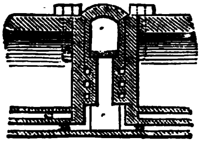


Fig. 94.
Vertical Section at the Junction with the Chimney.

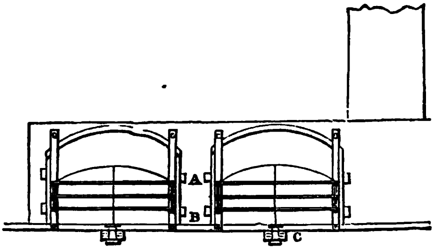


Fig. 95.—Elevation.

It is the duty of the coke-burner to watch the progress of the combustion by the eye-holes for that purpose, and to regulate the admission of air accordingly. When scarcely any flame can be observed to pass from the heated mass of fuel the air is altogether excluded for some time before the oven is ready to be "drawn" or "cooled," as the case may be.

Since, therefore, even with the most carefully arranged air-passages, much depends upon the care of the burner, there exists, as previously remarked, an opinion amongst experienced men that, with such care judiciously exercised, the cheaper class of ovens are nearly as good as the most expensive ones for all practical purposes. The Great Western Railway Company have had both classes of ovens, and found no material difference in the products, either in quantity or in quality. The Bristol and Exeter Railway ovens yielded about 13 cwt. of good coke, 6½ cwt. of small and waste coke, and some ashes, fit for lime-burners, from a ton of Cardiff coals. The coke was drawn out of the ovens hot, by a cradle similar to Cox's, Figs. 87, 88, which probably increases the comparative quantity of small to large coke.

CHAPTER VIII.

PEAT.

Peat, or turf, like coal, is a vegetable product; but it is comparatively light, fibrous, and spongy. The quality of peat is very variable, but generally it improves in proportion to its depth below the surface, owing partly to the more advanced decomposition of the constituent fibres, whereby the fibrous texture becomes lost, and partly to the dead pressure of the superincumbent load. It is of a light brown colour near the top, and of a darker brown lower down, until in the deeper bogs it becomes nearly black.

Peat, as it is cut from the bog, contains from 80 to 90 per cent. of water, and when air-dried it retains a proportion of water equal to from 15 to 25 per cent. of the whole weight. When dried it is light, and therefore bulky. Whilst a cubic yard and a quarter of heaped coal weighs a ton, it requires four or five cubic yards of dried turf of average quality to weigh a ton. The difficulty of drying peat, and its bulkiness when dry, constitute grave objections to its use as a fuel. The evaporative power of average peat is little more than a half of that of average coal, and it follows that, to effect the evaporation of an equal quantity of water, the volume of peat fuel required would amount to about eight times the volume of coal. The desiderata for the manufacture of good peat fuel are, therefore, a cheap method of drying and the condensation of the peat. Dense peat is excellent as a generator of steam; and though it is much inferior to coal in heating power, it leaves a minimum of clinker, and it does not concentrate the heat, in burning, with local intensity upon the boiler, as occasionally happens in burning coal.

The manufacture of peat-fuel is conducted in three different ways: producing ordinary cut turf, turf compressed by mechanical force, and condensed turf, made by the maceration or the tearing up and mixing of raw fibrous peat. The great advantage of the condensing process is obvious, when it is considered that it effects a reduction of bulk, and consequent increase of solidity and specific gravity, of from 2½ to 3 times those of the untreated material, as evidenced by the following comparative weights of peat:—

Ordinary cut peat, air-dried, average weight (say)	20	lbs.	per c. ft.
Dense peat, from upper strata	40	„	„
„ middle strata	62½	„	„
„ lowest strata	73	„	„

The following is an analysis, by Dr. Cameron, of peat from an estate in Galway, of which three samples were submitted to him:—

"No. 1, the densest of the three specimens: 100 parts contain—

Moisture	29·34
Carbon	42·03
Hydrogen	5·08
Nitrogen	1·65
Oxygen	17·5
Sulphur	0·60
Ash	3·80
	100·00
Coke	31·30

"A specimen of turf marked No. 2 is still better, containing only 22·57 per cent. of moisture and 2·32 per cent. of ash."

With regard to the heating power of peat, it may be stated that the results of a long course of comparative trials of peat and coal, during alternate fortnights, at Messrs. Guinness's Brewery, in Dublin, proved conclusively that, for generating steam, the efficiency of the peat was just one-half of that of coal.

On the Continent, peat is very much used in locomotive engines, and it has frequently been tried in this country for the same purpose. About the year 1840, Lord Willoughby d'Eresby had some peat tried in the *Hesperus* locomotive, on the Great Western Railway. This engine was of Hawthorn's return-tube construction, and required, it was reported, about a third more of peat than of coke, with equal forces of draught. The peat was of a medium quality, and of a brown colour.

According to the reports of other trials, in locomotives and in steamboats, peat-fuel was more effective, weight for weight, than coal, as fuel. There must have been some mistake in the trials or in the reports, and it is most probable that the efficiency of peat is really about one-half that of coal, taking average qualities. This conclusion is confirmed by the experience on the Continent.

CHAPTER IX.

GENERAL NOTIONS ON STEAM.

Steam, in a popular sense, is the name given to the visible, moist vapour which arises from bodies which contain juices easily expelled from them by heat, though the heat may not be sufficient for the combustion of the bodies. Thus there is the steam of boiling water, of malt, of a tan-bed. Steam rises in abundance from bodies when they are heated, forming a white cloud, which diffuses itself, and disappears at no very great distance from the bodies from which it was disengaged. In this case the surrounding air is found loaded with water or moisture; the steam ultimately being completely dissolved in the air, and composing while thus united a transparent elastic fluid. Here the steam has passed through the three stages of invisibility, visibility, and invisibility; for steam at the instant of generation is invisible and perfectly transparent, and if isolated from air it continues to be invisible and perfectly colourless, like air, but it appears in the form of an opaque-white cloud when first mixed with air, and continues to be visible until it has been dissolved in the air. If a teakettle boils violently, so that the steam issues from the spout in great abundance, it may be observed that the visible cloud is not formed at the very mouth of the spout, but at a small distance before it, when it begins to mingle with the surrounding air. Ultimately, the cloud disappears in the atmosphere of the room, when the vapour has become completely dissolved in the air.

Steam is, then, an elastic fluid, vaporised water, as water is liquefied ice.

We are most familiar with steam when in the act of rising violently from heated water in the process of ebullition, and its phenomena may be studied with advantage by examining it in a glass vessel placed over a strong lamp. When heat is first applied, a rapid circulation of the fluid ensues. The water on the bottom being first heated and expanded, becoming lighter than the rest, rises to the top, and is replaced by the current of colder water descending, to receive in its turn a further accession of heat. Afterwards, small globules of steam, formed on the bottom and surrounded by a film of water, are observed adhering to the glass; as the heat increases, they enlarge; in a short time several of them unite, form a bubble larger than the others, and, detaching themselves from the glass, rise upwards in the fluid. But they never reach the surface; they encounter currents of water still comparatively cold, and descending to receive from the bottom their supply of heat; and, encountering them, the bubbles are robbed of their heat, shrivel up into their original bulk, and are lost among the other particles of water. In a short time the mass of water becomes more uniformly heated, the bubbles, becoming larger and more frequent, are condensed with a loud crackling noise, and at last, when the whole mass reaches the temperature 212° Fahrenheit, the bubbles rise through the water without being condensed, swell and unite with others as they rise, and burst out upon the air in a copious volume of steam, of the same temperature as the water from which they are formed, and, pushing aside the air, make room for themselves. In this process, by continuing the application of heat, the whole of the water may be "boiled away," or converted into steam.

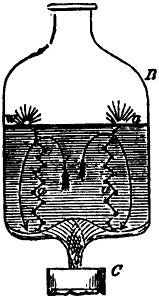


Fig. 96.—Water Boiling.

For example, let the glass phial B, Fig. 96, represent a boiler filled with water to W, and placed over the flame of the candle C. At first, there is no visible circulation in the water, but it soon begins, and continues to increase until small globules are observed to form at the bottom from some of the descending atoms of water, and as soon as formed dart off in an irregular zigzag ascent to the surface, retaining their spherical form. The circulation increases until ebullition commences, and larger and more numerous globules are formed, crossing each other's paths in their ascent to the top, where they expand into steam nearly 1,700 times more voluminous than the water enclosing the globule. In the figure, only two of these atoms of water, *a a*, *a a*, are represented, to make the process more obvious.

It is also to be remarked that the temperature of the steam issuing from boiling water is the same as the temperature of the water itself, and remains equally invariable; so that all the steam produced from water boiling at 212°, is itself at 212°. It is manifest that the heat which the fire gives out during the time of ebullition is carried off by the large volumes of steam that are diffused through the air, and so it happens that an increase of heat in the fire, instead of increasing the heat in the water, only increases the volumes of steam thrown off and the quantity of heat carried away.

This view of the subject is confirmed by a simple experiment. Place a strong flask containing water, having a thermometer among the water, over a lamp until the water boils. The thermometer will be observed rising till it reaches 212°, when the steam will begin to escape rapidly from the neck of the flask. Let the flask now be corked tightly, and the heat continually applied, it will then be observed that the thermometer does not now stand at 212°, but rises visibly from this point to 220° and 230°, showing that the free escape of the steam into the open air is necessary in order that the boiling-point, as it is called, may remain stationary. And, further, if the cork be withdrawn from the flask, whilst the heat of the lamp is still applied, the vapour will instantly rush out in a large volume, and the thermometer will sink and return to 212°, where it will remain, showing that all the excess of heat has been carried off by the steam into the air.

It is evident from the foregoing consideration that a large quantity of heat is appropriated and carried off by the steam of the quantity of which the thermometer affords no indication, although the same heat that produced the state of ebullition be continually applied; and although this heat continuously enters the water, yet it is not detected by the thermometer The heat that becomes thus insensible, or hidden in the steam, is said to become latent, and is known as *latent heat.* The term is not, however, strictly exact, for the quantity of heat thus apparently rendered insensible may be discovered and measured by means of other appliances. With this qualification, it is a useful expression, and is characteristic of the phenomena of the constituent heat of steam.

But the question arises, Why does water require to be heated up to 212° before it will throw off steam into the atmosphere? May it not throw off the steam at a lower temperature? The reply is, that the elastic force of the heat is not sufficient to enable the steam to force its way against the pressure of the air until it reaches the temperature of 212°. In proof of this assertion, it may be stated that when the pressure of the air on the surface of the water is diminished by artificial means, the steam does actually rise, and the water bubbles and boils with great violence at temperatures much below 212°. Thus, when water is heated under a pressure only one-half of the atmospheric pressure, it boils at a temperature of 180°; and when the pressure is diminished to one-fifteenth of that of the air, it will boil at a temperature as low as 102°.

The phenomena of the condensation of steam by cold, on which the action of the condensing steam-engine depends, is the inverse of the generation of steam by heat. If a body of steam be placed in contact with any body cooler than itself, as iron, wood, or water, it is instantly condensed by the body to a greater or less extent; and the condensing process is continued until the temperature of the body is raised to an equality with that of the steam, by the heat disengaged from the steam at the moment of condensation, or until the whole of the steam is condensed into water.

CHAPTER X.

INVESTIGATIONS ON THE PROPERTIES OF STEAM.

The earliest-known researches into the phenomena of steam, undertaken with a philosophical purpose, are those of J. Henrico Ziegler, published by him in 1769. He allowed atmospheric air to mingle with the steam to such an extent as greatly to vitiate the results.

M. Betancourt, about the end of last century, made a series of experiments on the force of the vapour of water, alcohol, and other liquids at various temperatures. Some of his experiments were made *in vacuo,* and he seems to have been one of the first philosophers who examined the production of steam at temperatures below the ordinary point of ebullition under the pressure of the atmosphere. His experiments extended from 32° up to 279°, being 67° above the ordinary boiling-point, and the precautions which he adopted for the removal of atmospheric air from intermixture with the vapours gave his experiments considerable precision and value.

Dr. Robinson was one of the first, in this country, to make accurate and systematic experiments on the temperature and pressure of steam, about the year 1778; though Mr. Watt, in 1764-65, made roughly some experiments, from which he laid down a curve to represent the relation of the temperature and the pressure, in which he says, "the abscissæ represented the temperatures, and the ordinates the pressures, and thereby found the law by which they were governed, sufficiently near for my then purpose." In 1773-74 he resumed his experiments, which were repeated by Mr. Southern and Mr. Creighton, in 1803, with the view of ascertaining the density of steam at pressures below as well as above that of the atmosphere; extending from a pressure of 0·4 inch to 240 inches of mercury, or eight atmospheres. Dr. Dalton, in 1793 and 1802, published the results of his experiments; and, subsequently, Dr. Ure, in 1817, Mr. Philip Taylor, and Professor Arberger of Vienna, experimented on high-pressure steam through an extensive range of temperatures.

A commission of the French Academy were appointed to investigate systematically the phenomena of steam. They completed their labours in 1829, the investigation having been conducted principally by MM. Arago and Dulong. The results of their observations, which were carried as high as to twenty-four atmospheres of pressure, or about 360 lbs. per square inch, were published in 1831. In 1830, a committee of the Franklin Institute, of the State of Pennsylvania, United States, was appointed to examine into the causes of the explosion of steam-boilers. They experimented on the pressure and temperature of steam at pressures varying from 1½ to 10 atmospheres. In 1844, Professor Magnus published a memoir on the expansive force of steam, in which he noticed the defects of previous investigations.

In July, 1844, M. V. Regnault published his very valuable memoir on the "Elastic Force of Aqueous Vapour," in the *Annales de Chimie et de Physique*, and afterwards more fully in the memoirs of the Institute, in 1847. M. Regnault repeated the methods of Dalton, Ure, Magnus, Dulong, and Arago, and he pointed out the defects under which they laboured, and the limits between which their results could be relied on. His experimental observation extended from a temperature 25·6° Fahrenheit below 0° or zero, at which the pressure was less than 0·006 lb. on the square inch, to 446° Fahrenheit, at which the pressure is over 400 lbs. on the square inch.

Apparatus for Testing the Properties of Steam, with some Results of Observations.

The relations of temperature and pressure of steam are those which, as the simplest and the most direct, have most engaged the attention of investigators. Under the pressure of the atmosphere, which is 14·7 lbs. per square inch, the temperature is designated 212° Fah.; and from this temperature, above and below, all others are reckoned, corresponding to the greater or less pressures under which the steam is generated. When the atmospheric pressure is withdrawn by means of an air-pump, water has been observed to boil at as low a temperature as 70°, producing steam having a pressure of about ·33 lb. per square inch, or ·72 inch of mercury. If water be boiled in a glass phial, and corked whilst it still contains steam, it will, on being withdrawn from the heat, cease to boil; but if immersed in cold water boiling would recommence, because the cold had condensed the steam and removed the pressure from the water; but if again immersed in hot water steam would be formed, and the boiling cease from the increased pressure on the water. It is found approximately by experiment that for every variation of one inch of mercury, or one-half pound of the pressure on the water, the boiling-point, within a narrow limit of range, varies 1·76°, as under:—

Barometer in Mercury.	Boiling Point. Fahr.
27	206·9
27½	207·8
28	208·7
28½	209·5
29	210·4
29½	211·2
30	212 0
30½	212·8
31	213·6

Steam is produced at all temperatures; even at the freezing-point, vapour is produced, and it possesses mechanical force even at such a low temperature, as is shown in the following Table by Dalton :—

TABLE No. XXIII.

ELASTIC FORCE OF STEAM FROM 32° TO 212° IN INCHES OF MERCURY.

Temp. Deg.	Force In. mer.	Temp. Deg.	Force. In. mer.	Temp. Deg.	Force. In. mer.	Temp. Deg.	Force. In. mer.	Temp. Deg.	Force. In. mer.
32	0·200	69	0·698	105	2·18	141	5·90	177	14·22
33	0·207	70	0·721	106	2·25	142	6·05	178	14·52
34	0·214	71	0·745	107	2·32	143	6·21	179	14·83
35	0·221	72	0·770	108	2·39	144	6·37	180	15·15
36	0·229	73	0·796	109	2·46	145	6·53	181	15·50
37	0·237	74	0·823	110	2·53	146	6·70	182	15·86
38	0·245	75	0·851	111	2·60	147	6·87	183	16·23
39	0·254	76	0·880	112	2·68	148	7·05	184	16·61
40	0·263	77	0·910	113	2·76	149	7·23	185	17·00
41	0·273	78	0·940	114	2·84	150	7·42	186	17·40
42	0·283	79	0·971	115	2·92	151	7·61	187	17·80
43	0·294	80	1·00	116	3·00	152	7·81	188	18·20
44	0·305	81	1·04	117	3·08	153	8·01	189	18·60
45	0·316	82	1·07	118	3·16	154	8·20	190	19·00
46	0·328	83	1·10	119	3·25	155	8·40	191	19·42
47	0·339	84	1·14	120	3·33	156	8·60	192	19·86
48	0·351	85	1·17	121	3·42	157	8·81	193	20·32
49	0·363	86	1·21	122	3·50	158	9·02	194	20·77
50	0·375	87	1·24	123	3·59	159	9·24	195	21·22
51	0·388	88	1·28	124	3·69	160	9·46	196	21·68
52	0·401	89	1·32	125	3·79	161	9·68	197	22·13
53	0·415	90	1·36	126	3·89	162	9·91	198	22·69
54	0·429	91	1·40	127	4·00	163	10·15	199	23·16
55	0·443	92	1·44	128	4·11	164	10·41	200	23·64
56	0·458	93	1·48	129	4·22	165	10·68	201	24·12
57	0·474	94	1·53	130	4·34	166	10·96	202	24·61
58	0·490	95	1·58	131	4·47	167	11·25	203	25·10
59	0·507	96	1·63	132	4·60	168	11·54	204	25·61
60	0·524	97	1·68	133	4·73	169	11·83	205	26·13
61	0·542	98	1·74	134	4·86	170	12·13	206	26·66
62	0·560	99	1·80	135	5·00	171	12·43	207	27·20
63	0·578	100	1·86	136	5·14	172	12·73	208	27·74
64	0·597	101	1·92	137	5·29	173	13·02	209	28·29
65	0·616	102	1·98	138	5·44	174	13·32	210	28·84
66	0·635	103	2·04	139	5·59	175	13·62	211	29·41
67	0·655	104	2·11	140	5·74	176	13·92	212	30 00
68	0·676								

To produce steam of a pressure greater than the atmosphere requires the water to be boiled in a close vessel until it has attained the force necessary to perform its mechanical duty. The gradual accumulation of that force in a steam-boiler, and the ratio of the temperature to that force, are illustrated in Fig. 97, which represents a spherical boiler partly filled with mercury and partly filled with water. B, a barometric glass tube open at both ends, reaching nearly to the bottom of the mercury. A thermometer is shown with its end reaching nearly to the surface of the water. D, the supply cock for filling the boiler. On heat being applied below the boiler whilst the supply cock D is open, the steam will pass out as it is formed, at a temperature of 212°, and the mercury will remain stationary, since the pressure of the atmosphere on it in the tube B is equal to the pressure of the steam on the water in the boiler A. If D be then shut, this equality of pressure ceases, and the mercury begins gradually to ascend the tube in the ratio of the accumulating force of the steam above the force of the atmosphere. The thermometer also rises by the increased temperature of the steam. Now, if the pressure of the steam has raised the mercury 15 inches in the tube B, indicating a force of 7½ lbs. above that of the atmosphere, the thermometer will have risen to 234°, being the measure of the heat at that pressure. At 250°, the mercury in the tube will have risen 30 inches, showing a pressure of 15 lbs. above the atmosphere with a temperature of 250°, or an absolute pressure of 30 lbs. per square inch on the water. If the cock D be now opened the steam will rush out, and the thermometer will rapidly fall to 212°, the mercury in the tube B

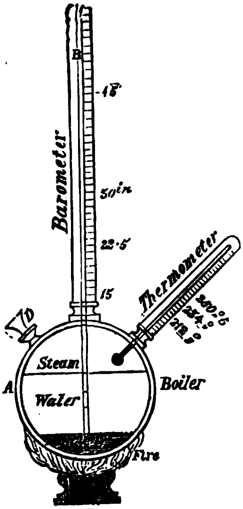


Fig. 97.

returning to zero. The elastic or mechanical force of steam increases in a greater ratio than its temperature, for at 212° its force is 15 lbs., at 250° it is 30 lbs., and at 284° it is 52½ lbs. The first 38° increases the force 15 lbs., but by 34° more heat its force is increased 22½ lbs.

In the experiments conducted for the French Academy by MM. Arago and Dulong, the pressure of steam was tested by means of a barometric tube filled with mercury. It was made in thirteen pieces, each 78¾ inches long, to join together so as to form one enormous glass tube, having a bore of about one-fifth of an inch diameter for the mercurial column. This was erected against the old church tower of Genevieve, and experiments made to determine the accuracy of Mariotte's law of air, that its pressure or force is inversely as the space a given quantity is made to occupy. Having found this law very nearly correct to the high pressure of 24 atmospheres, and as the fears of the authorities for the old tower from an explosion of the boiler led to the large barometer being taken down, they employed carefully constructed air-gauges similar to Figs. 69, 70, to determine the force of the steam. One thermometer was placed in the boiler to ascertain the temperature of the steam, as in Fig. 97, and another placed nearly to the bottom of the water, that the temperatures of both water and steam might be ascertained at the same time. They were found to correspond exactly, the steam being of the same temperature as the water which produced and was in contact with it.

The compression of the air in the gauge, by the force of the steam acting on the mercury, indicated its pressure at the same time, so that the pressure and temperature were simultaneously determined up to 24 atmospheres, and by calculation extended to 50 atmospheres, as given in the following Table:—

TABLE No. XXIV.

MESSRS. ARAGO AND DULONG'S EXPERIMENTS OF THE TEMPERATURE AND PRESSURE OF STEAM.

Atmospheres.	Deg. Fah.	Deg. Cent.	lbs. per Inch.	Kilogrammes per sq. Centimtr.
1	212	100	14·706	1·0335
1½	233·96	112·2	22·059	1·5502
2	250·52	121·4	29·412	2·067
2½	263·84	128·8	36·765	2·5837
3	275·18	135·1	44·118	3·1005
3½	285·08	140·6	51·471	3·6172
4	293·72	145·4	58·824	4·134
4½	300·30	149·6	66·177	4·6507
5	307·54	153·1	73·53	5·1675
5½	314·24	156·8	80·883	5·7842
6	320·36	160·2	88·236	6·2010
6½	326·26	163·48	95·589	6·7177
7	331·70	166·5	102·942	7·2345
7½	336·86	169·37	110·295	7·7512
8	341·78	172·1	117·648	8·268
9	350·78	177·1	132·354	9·3015
10	358·88	181·6	147·060	10·3350
11	366·85	186·0	161·766	11·3685
12	374·00	190·0	176·472	12·402
13	380·66	193·7	191·178	13·435
14	386·94	197·19	205·884	14·469
15	392·86	200·48	220·59	15·5025
16	398·48	203·6	235·296	16·536
17	403·82	206·5	250·002	17·5695
18	408·92	209·4	264·708	18·6030
19	413·78	212·2	279·414	19·6365
20	418·46	214·7	294·120	20·67
21	422·96	217·2	308·826	21·7035
22	427·28	219·6	323·532	22·7370
23	431·42	221·9	338·238	23·7705
24	435·56	224·2	352·944	24·8040
25	439·34	226·3	367·650	25·8375
30	457·16	236·2	441·18	31·005
35	472·73	244·85	514·71	36·1725
40	486·59	252·55	588·24	41·34
45	499·13	259·52	661·77	46·5075
50	510·60	265·89	735·33	51·6750

In 1832-3 the Franklin Institute of America made a series of elaborate experiments to determine the latent heat in steam of from 212° to 215°, by condensing a given weight of steam in a given quantity of water.

Fig. 98 shows the method adopted and the care exercised to obtain accurate results. F, the boiler into which the copper vessel L, containing the heater S, was placed to sustain the temperature of the boiler during the trial. W, *k*, *g*, a pipe for conveying the steam to the condenser A, filled with a known quantity of water. The steam was allowed to flow from the boiler and condense until the condenser was filled, when it was shut off by the cock *k*. The condenser and contents being then accurately weighed showed the weight of steam which had been condensed, and the thermometer *t* showed the increase of the temperature of the water in A. Of the three other thermometers, *e* showed the temperature of the steam, *i* the temperature within the radiation protector B, and *o* the surrounding temperature of the apartment.

These thermometers were all carefully adjusted and corrections made for their respective duties, and both condenser and boiler incased to prevent loss of heat by radiation. A reflecting tin plate, P, was also placed between them, to guard against the least influence from the boiler affecting the condenser.

The principal results are given in Table No. 25.

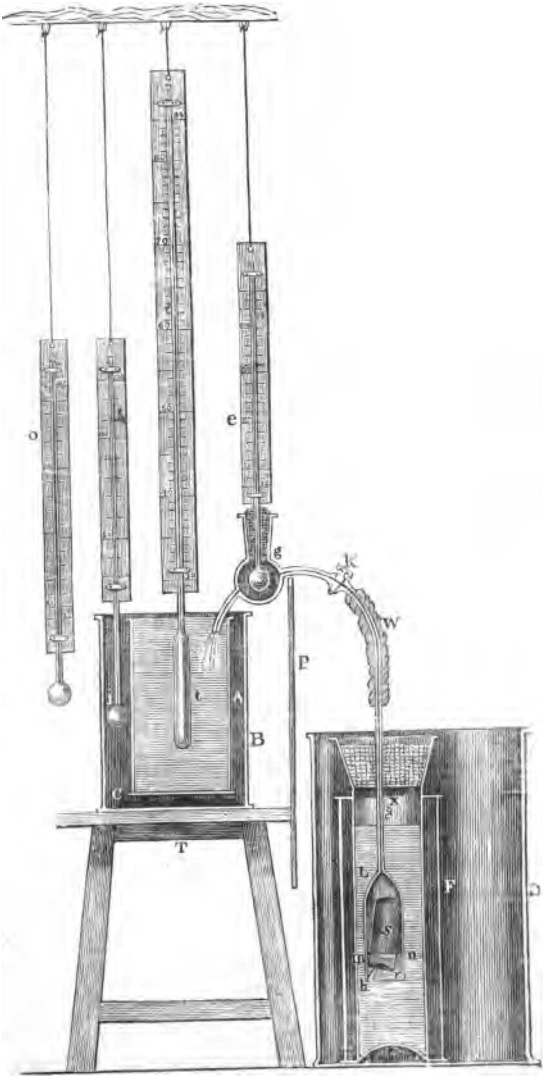


Fig. 98.

TABLE No. XXV.

LATENT HEAT IN STEAM, FRANKLIN INSTITUTE.

STEAM.			WATER.				LATENT HEAT.	
Temp. before condensation.	Temp. lost by condensation.	Quantity condensed.	Condenser, made of.	Quantity in condenser.	Temp. before the admission of steam.	Temp. increased by the condensation of the steam admitted.	In each experiment.	Mean of experiments.
Fah.	Fah.	Grains.	Material.	Grains.	Fah.	Fah.	Fah.	Fah.
214	127·5	347	thin copper	38659	75·35	10·75	1086·5	
215	129·25	504	”	38659	70·9	14·85	1025·5	
215	139·25	241	”	39305	68·75	7	1018·95	
214	136·75	250	”	39305	70	7·25	1019·55	
								1037·87
213	120·35	299	thick glass	17112	74·6	18·05	996·9	
215	127	192	”	17112	75·5	12·5	1077·82	
214	139·5	156	”	17428	64·6	9·9	1044·8	
213	139·75	127	”	17428	65·25	8	1035·75	
								1038·51
213	134·2	167	thin glass	18405	68·5	10	987·3	
212	143·5	156	”	17428	58·5	10	1003·3	
								995 3
213	123·8	169	thick sheet iron	13152	75·1	14·1	1027·2	
214	124·2	190	”	13152	73·7	16·1	1043·5	
								1035·35

Having made these experiments on latent heat, the Committee extended their researches to ascertain the relation between the temperature of the steam and its elastic force. For this purpose they employed a small boiler 12 inches diameter and 34½ inches long, having a glass window in each end for observation, besides the usual gauge-cock and glass water-gauge. A mercurial cistern was attached to the boiler, and into the cistern was fitted, steam tight, an air-gauge 26·43 inches long, of the class of Fig. 69, having its open end in the mercury. A scale of pressures having been carefully adjusted to this gauge-tube, thermometers were applied to test the temperature of the water and of the steam in the boiler. Much care was taken to obtain accurate accounts from the pressure of the steam on the gauge, and to note at the same time the temperature indicated by the thermometers.

As with all other experiments on steam and water in contact with each other, the temperature was ascertained to be the same in both.

When the first trials were completed, it was found that they differed considerably from those of the French Academy, when they were repeated with all the advantages of experience and precaution gained from the first series. The results of both series are given in Tables Nos. 26 and 27; and Table No. 28 contains a summary of the pressures advancing by half-atmospheres, and the relative temperatures.

TABLE No. XXVI.

ELASTIC FORCE OF STEAM BY THE FRANKLIN INSTITUTE.

(*First Series of Experiments.*)

Temp. of steam.	Temp. of air in steam-gauge.	Volumes of air at 48°.	Height of mercury in steam gauge.	Compressure on air in steam-gauge equal to	Total elasticity per square inch, in	
Fahr.	Fahr.	Vols.	In. mer.	In. mer.	In. mer.	Atmos. of 30 in. mer.
262¼	74	3·737	15·04	59·09	72·99	2·43
268½	”	3·259	16·34	67·76	82·97	2·76
275½	”	2·898	17·34	76·20	92·42	3·08
286½	”	2·319	18·94	95·23	113·07	3·77
296½	”	1·948	19·94	113·36	132·21	4·41
298½	”	1·891	20·11	116·76	135·80	4·53^{2}
302	”	1·767	20·44	124·98	144·33	4·81^{3}
305½	75	1·641	20·79	134·57	154·28	5·14
313¼	”	1·422	21·39	155·30	175·61	5·85^{4}
317¾	”	1·332	21·64	165·79	186·36	6·21
320¾	76	1·255	21·79	173·20	193·92	6·46
327¾	”	1·113	22·24	198·41	219·14	7·30
333¾	”	0·950	22·69	232·46	254·09	8·47

TABLE No. XXVII.

ELASTIC FORCE OF STEAM BY THE FRANKLIN INSTITUTE.

(Second Series of Experiments.)

Temp. of steam.	Temp. of air in steam-gauge.	Volumes of air at 48°	Height of mercury in steam-gauge.	Compressure on air in steam-gauge equal to	Total elasticity per square inch, in	
Fahr.	Fahr.	Vols.	In. mer.	In. mer.	In. mer.	Atmos. of 30 in. mer.
248¼	53	4·277	14·04	46·19	59·08	1·97
269½	52	3·026	17·34	65·29	81·51	2·72
284½	„	2·152	19·64	91·76	110·30	3·68
289½	„	1·974	20·06	100·05	119·02	3·97
294½	53	1·802	20·56	109·63	129·11	4·30
299½	54	1·611	21·04	122·66	142·62	4·75
304½	54½	1·500	21·34	131·66	151·92	5·06
310¼	„	1·382	21·64	142·94	163·51	5·45
314¾	55	1·233	22·04	160·26	181·23	6·04
319¾	55½	1·124	22·34	175·86	197·13	6·57
329¾	56	0·937	22·84	210·84	232·62	7·75
334½	57	0·904	22·94	218·60	240·48	8·02
338¾	57½	0·870	23·04	226·92	548·92	8·30
345	„	0·805	23·24	245·44	267·62	8·92
348	58	0·771	23·34	256·05	278·33	9·28
350	„	0·737	23·44	267·97	290·35	9·68
352	„	0·719	23·50	274·92	297·36	9·91
346	62	0·785	23·28	251·78	274·00	9·13

TABLE No. XXVIII.

MEAN ELASTIC FORCE OF STEAM, DEDUCED FROM THE FRANKLIN EXPERIMENTS IN ATMOSPHERES.

Pressure.	Observed Temp.	Pressure.	Observed Temp.	Pressure.	Observed Temp.	Pressure.	Observed Temp.
Atmos.	Fahr.	Atmos.	Fahr.	Atmos.	Fahr.	Atmos.	Fahr.
1	212	3½	384	6	315½	8½	340½
1½	235	4	291½	6½	321	9	345
2	250	4½	298½	7	326	9½	349
2½	264	5	304½	7½	331	10	352½
3	275	5½	310	8	336		

There is not room in this place to describe the various apparatus employed by M. Regnault in prosecuting his observations on the properties of steam. The results of the observations of Regnault have been thoroughly discussed and reduced to order and formulas for practical purposes, in the article *Steam*, in the eighth edition of the "Encyclopædia Britannica," contributed by Mr. D. K. Clark, of which some use will be made in what follows with regard to the properties of steam. In the same article is given an illustrated description of Regnault's experimental apparatus.

CHAPTER XI.

BOILING POINTS.

THE boiling point, or the temperature at which ebullition and evaporation commence, is always the same for the same liquid under the same circumstances. This constant point depends on the nature of the liquid: for the following liquids, the boiling points, at atmospheric pressure, are as follows:—

	Degrees Fahr.
Mercury	648
Oil and grease, mean	599
Sulphuric acid	590
Pure water	212
Common alcohol	173
Chloroform	140
Sulphuret of carbon	118
Ether	100

The pressure exerted on the surface of the liquid being opposed to the generation and disengagement of the globules of vapour in proportion to its intensity, it follows that there are as many different boiling points for the same liquid as there may be different pressures on its surface. Pure water, at the level of the sea, under atmospheric pressure, boils at 212° Fah. But the higher the elevation above that level, the more is the atmospheric pressure diminished, and the boiling point reduced; whilst the lower the level below that of the sea, the greater is the pressure and the higher the boiling point. Ebullition is notably facilitated on high mountains; and retarded at low levels, or at the bottom of a deep mine. It is facilitated under the receiver of an air-pump, when the air is exhausted; and, on the contrary, retarded in a boiler under high pressure. The boiling point of water in the open air, at various localities, is as follows :—

	Degrees Fahr.
London	212
Mexico (Almshouse of Saint-Gothard)	198
Quito	194
Mount Blanc (16,000 feet above the level of the sea)	185

Foreign substances in suspension in water, as mud or sand, not chemically combined with it, do not appear to exercise any sensible influence on the position of the boiling point. But it is sensibly affected by substances in combination or in solution. Such substances as are more volatile than water, as ether and alcohol, when combined with water, lower its boiling point. Salts, on the contrary, raise the boiling point. For example, for water saturated with various salts, the boiling points are as follows :—

	Degrees Fahr.
Carbonate of soda	220·3
Sea salt	230
Sal ammoniac	237·6
Saltpetre	239
Soda	250
Carbonate of potash	275
Chloride of calcium	355

The nature of the boiler affects to some extent the evaporation of water; chiefly in this way, that the evaporation is freer according as the conducting power of the material is greater. In the order of conductibility, the metals are as follows :—1st, copper; 2nd, iron, which has only about two-fifths the conducting power of copper; 3rd, zinc and tin, about a third; 4th, lead, which has only about half the conducting power of zinc. As to brass, the more of zinc it contains, the less is its conducting power; but the proportion of 90 per cent. of copper to 10 per cent. of zinc makes a composition which acts very well as a conductor in the multitubular flues of locomotive boilers.

CHAPTER XII.

PRESSURE AND EXPANSION OF STEAM.

THE pressure of steam is equal in all directions, and it is usual to measure the pressure with reference to that of the atmosphere, which is equal to 14·7 lbs. per square inch of surface, and is the measure of one atmosphere of pressure. Vapours, of which steam is one, do not follow the law peculiar to permanent gases, according to which the volume of a given weight is inversely as the pressure. It has been demonstrated, on the contrary, that there exists a constant relation between the pressure, the density, and the temperature of steam; such that the pressure cannot be raised above a given maximum, without, at the same time, a certain elevation of temperature. If the volume be forcibly reduced, and the vapour compressed, without any change of temperature, the compression has not the effect of augmenting the pressure, as would happen if air was similarly treated: it only results in liquefying a portion of the steam, according as the volume is reduced, so that the volume, however reduced, will only contain so much proportionally the less of steam of the original pressure. In order to increase the pressure, the temperature must be raised. When the vapour has attained the limit of density and pressure, corresponding to the temperature, the steam is said to be saturated, and it is always in the state of saturation when in contact with water. For one pressure, there is one density and one temperature; and the higher the pressure, the greater is the density and the higher is the temperature.

But when a quantity of steam is placed out of contact with water, as in the cylinder of a steam-engine, it may be expanded, and again compressed up to the limit of saturation, and it will follow approximately, though not precisely, the law of Boyle or Mariotte; that is to say, the pressure is nearly in the inverse ratio of the volume, insomuch that when the volume is doubled, the pressure is reduced to about one-half, and when the volume is trebled, the pressure is reduced to about a third.

If, however, a quantity of saturated steam be superheated, it becomes amenable to the laws of permanent gases, and behaves as one of them, expanding and contracting in the inverse ratio of the volume, when the temperature is constant, without the condensation of any portion of it.

It follows—1st. That one density and one pressure relative to one temperature are attained in a steam boiler; these several quantities are in equilibrium, and the steam is in a state of saturation. 2nd. That so long as the state of saturation corresponding to a given temperature is not attained, evaporation continues; when attained, evaporation ceases. 3rd. If the capacity of the boiler be increased, evaporation is resumed, until the state of saturation is again arrived at. Likewise, if the temperature be increased, evaporation is resumed, and continues till the steam again becomes saturated. 4th. If the temperature falls, the pressure and the density fall also. 5th. If the boiler be closed, and the steam remain at the same temperature, the conditions remain unchanged. But, if an opening be made for the outflow of steam, the pressure will fall, and evaporation will be recommenced, until saturation is re-established. This new generation of steam is very rapid, so much so that the pressure does not sensibly vary between and during the charges of steam taken from the boiler for each stroke of the piston.

The annexed Table, No. 29, of the properties of saturated steam, is transcribed from the article *Steam* in the "Encyclopædia Britannica." The Table is calculated by means of the formulas given in that article, which are deduced from the experimental observations of M. Regnault. In the first column are given the pressures from 1 lb. to 200 lbs. total or absolute pressure per square inch. In the second column are the temperatures of saturated steam, of the pressures given in the first column. The third column contains the total heat of steam of the given temperatures, reckoned from 32° Fah.; that is, it is assumed that the water from which the steam is generated is supplied to the boiler at a temperature of 32° Fah., and that it is raised from 32° to the sensible temperature, as in the second column, preparatory to being converted into steam of the corresponding temperature and pressure. The fourth column contains the latent heat of the steam, being that which is consumed by the nascent steam in forcing its way into space, or forming itself, in addition to the heat required to separate the particles of the water and so convert it into vapour. The fifth column contains the density of the steam, expressed in pounds weight per cubic foot, as a measure of the quantity of matter in a given volume. The sixth column gives the volume of one pound of steam, which is the reciprocal of the density. By means of the values in the sixth column, the volume of any given weight of steam, compared with the volume or bulk of the water from which it is generated, may be readily calculated. But, to avoid the necessity for making such calculations, the seventh column is added, containing the relative volumes of steam of the several pressures, or the volume in cubic feet of steam generated from one cubic foot of water.

TABLE No. XXIX.

PROPERTIES OF SATURATED STEAM. BY D. K. CLARK.

Total Pressure per square inch.	Temperature.	Total Heat, reckoned from 32° Fahr.	Latent Heat.	Density or Weight of one cubic foot.	Volume of one pound of steam.	Relative Volume, or cubic feet of steam from one cubic foot of water.
lbs.	Fahr.	Fahr.	Fahr.	lb.	cubic feet.	Rel. vol.
1	102·1	1112·5	1042·9	·0030	330·36	20600
2	126·3	1119·7	1025·8	·0058	172·08	10730
3	141·6	1124·6	1015·0	·0085	117·52	7327
4	153·1	1128·1	1006·8	·0112	89·62	5589
5	162·3	1130·9	1000·3	·0138	72·66	4530
6	170·2	1133·3	994·7	·0163	61·21	3816
7	176·9	1135·3	990·0	·0189	52·94	3301
8	182·9	1137·2	985·7	·0214	46·69	2911
9	188·3	1138·8	981·9	·0239	41·79	2606
10	193·3	1140·3	978·4	·0264	37·84	2360
11	197·8	1141·7	975·2	·0289	34·63	2157
12	202·0	1143·0	972·2	·0314	31·88	1988
13	205·9	1144·2	969·4	·0338	29·57	1844
14	209·6	1145·3	966·8	·0362	27·61	1721
14·7	212·0	1146·1	965·2	·0380	26·36	1642
15	213·1	1146·4	964·3	·0387	25·85	1611
16	216·3	1147·4	962·1	·0411	24·32	1516
17	219·6	1148·3	959·8	·0435	22·96	1432
18	222·4	1149·2	957·7	·0459	21·78	1357
19	225·3	1150·1	955·7	·0483	20·70	1290
20	228·0	1150·9	952·8	·0507	19·72	1229
21	230·6	1151·7	951·3	·0531	18·84	1174
22	233·1	1152·5	949·9	·0555	18·03	1123
23	235·5	1153·2	948·5	·0580	17·26	1075
24	237·8	1153·9	946·9	·0601	16·64	1036
25	240·1	1154·6	945·3	·0625	15·99	996
26	242·3	1155·3	943·7	·0650	15.38	958
27	244·4	1155·8	942·2	·0673	14·86	936
28	246·4	1156·4	940·8	·0696	14·37	895
29	248·4	1157·1	939·4	·0719	13·90	866
30	250·4	1157·8	937·9	·0743	13·46	838
31	252·2	1158·4	936·7	·0766	13·05	813
32	254·1	1158·9	935·3	·0789	12·67	789
33	255·9	1159·5	934·0	·0812	12·31	767
34	257·6	1160·0	932·8	·0835	11·97	746
35	259·3	1160·5	931·6	·0858	11·65	726
36	260·9	1161·0	930·5	·0881	11·34	707
37	262·6	1161·5	929·3	·0905	11·04	688
38	264·2	1162·0	928·2	·0929	10·76	671
39	265·8	1162·5	927·1	·0952	10·51	655
40	267·3	1162·9	926·0	·0974	10·27	640
41	268·7	1163·4	924·9	·0996	10·03	625
42	270·2	1163·8	923·9	·1020	9·81	611

Total Pressure per square inch.	Temperature.	Total Heat, reckoned from 32° Fahr.	Latent Heat.	Density or Weight of one cubic foot.	Volume of one pound of steam.	Relative Volume or cubic feet of steam from one cubic foot of water.
lbs.	Fahr.	Fahr.	Fahr.	lb.	cubic feet.	Rel. vol.
43	271·6	1164·2	922·9	·1042	9·59	598
44	273·0	1164·6	921·9	·1065	9·39	585
45	274·4	1165·1	920·9	·1089	9·18	572
46	275·8	1165·5	919·9	·1111	9·00	561
47	277·1	1165·9	919·0	·1133	8·82	550
48	278·4	1166·3	918·1	·1156	8·65	539
49	279·7	1166·7	917·2	·1179	8·48	529
50	281·0	1167·1	916·3	·1202	8·31	518
51	282·3	1167·5	915·4	·1224	8·17	509
52	283·5	1167·9	914·5	·1246	8·04	500
53	284·7	1168·3	913·6	·1269	7·88	491
54	285·9	1168·6	912·8	·1291	7·74	482
55	287·1	1169·0	912·0	·1314	7·61	474
56	288·2	1169·3	911·2	·1336	7·48	466
57	289·3	1169·7	910·4	·1364	7·36	458
58	290·4	1170·0	909·6	·1380	7·24	451
59	291·6	1170·4	908·8	·1403	7·12	444
60	292·7	1170·7	908·0	·1425	7·01	437
61	293·8	1171·1	907·2	·1447	6·90	430
62	294·8	1171·4	906·4	·1469	6·81	424
63	295·9	1171·7	905·6	·1493	6·70	417
64	296·9	1172·0	904·9	·1516	6·60	411
65	298·0	1172·3	904·2	·1538	6·49	405
66	299·0	1172·6	903·5	·1560	6·41	399
67	300·0	1172·9	902·8	·1583	6·32	393
68	300·9	1173·2	902·1	·1605	6·23	388
69	301·9	1173·5	901·4	·1627	6·15	383
70	302·9	1173·8	900·8	·1648	6·07	378
71	303·9	1174·1	900·3	·1670	5·99	373
72	304·8	1174·3	899·6	·1692	5·91	368
73	305·7	1174·6	898·9	·1714	5·83	363
74	306·6	1174·9	898·2	·1736	5·76	359
75	307·5	1175·2	897·5	·1759	5·68	353
76	308·4	1175·4	896·8	·1782	5·61	349
77	309·3	1175·7	896·1	·1804	5·54	345
78	310·2	1176·0	895·5	·1826	5·48	341
79	311·1	1176·3	894·9	·1848	5·41	337
80	312·0	1176·5	894·3	·1869	5·35	333
81	312·8	1176·8	893·7	·1891	5·29	329
82	313·6	1177·1	893·1	·1913	5·23	325
83	314·5	1177·4	892·5	·1935	5·17	321
84	315·3	1177·6	892·0	·1957	5·11	318
85	316·1	1177·9	891·4	·1980	5·05	314
86	316·9	1178·1	890·8	·2002	5·00	311
87	317·8	1178·4	890·2	·2024	4·94	308
88	318·6	1178·6	889·6	·2044	4·89	305
89	319·4	1178·9	889·0	·2067	4·84	301

Total Pressure per square inch.	Temperature.	Total Heat, reckoned from 32° Fahr.	Latent Heat.	Density or Weight of one cubic foot.	Volume of one pound of steam.	Relative Volume, or cubic feet of steam from one cubic foot of water.
lbs.	Fahr.	Fahr.	Fahr.	lb.	cubic feet.	Rel. vol.
90	320·2	1179·1	888·5	·2089	4·79	298
91	321·0	1179·3	887·9	·2111	4·74	295
92	321·7	1179·5	887·3	·2133	4·69	292
93	322·5	1179·8	886·8	·2155	4·64	289
94	323·3	1180·0	886·3	·2176	4·60	286
95	324·1	1180·3	885·8	·2198	4·55	283
96	324·8	1180·5	885·2	·2219	4·51	281
97	325·6	1180·8	884·6	·2241	4·46	278
98	326·3	1181·0	884·1	·2263	4·42	275
99	327·1	1181·2	883·6	·2285	4·37	272
100	327·9	1181·4	883·1	·2307	4·33	270
101	328·5	1181·6	882·6	·2329	4·29	267
102	329·1	1181·8	882·1	·2351	4·25	265
103	329·9	1182·0	881·6	·2373	4·21	262
104	330·6	1182·2	881·1	·2393	4·18	260
105	331·3	1182·4	880·7	·2414	4·14	257
106	331·9	1182·6	880·2	·2435	4·11	255
107	332·6	1182·8	879·7	·2456	4·07	253
108	333·3	1183·0	879·2	·2477	4·04	251
109	334·0	1183·3	878·7	·2499	4·00	249
110	334·6	1183·5	878·3	·2521	3·97	247
111	335·3	1183·7	877·8	·2543	3·93	245
112	336·0	1183·9	877·3	·2564	3·90	243
113	336·7	1184·1	876·8	·2586	3·86	241
114	337·4	1184·3	876·3	·2607	3·83	239
115	338·0	1184·5	875·9	·2628	3·80	237
116	338·6	1184·7	875·5	·2649	3·77	235
117	339·3	1184·9	875·0	·2652	3·74	233
118	339·9	1185·1	874·5	·2674	3·71	231
119	340·5	1185·3	874·1	·2696	3·68	229
120	341·1	1185·4	873·7	·2738	3·65	227
121	341·8	1185·6	873·2	·2759	3·62	225
122	342·4	1185·8	872·8	·2780	3·59	224
123	343·0	1186·0	872·3	·2801	3·56	222
124	343·6	1186·2	871·9	·2822	3·54	221
125	344·2	1186·4	871·5	·2845	3·51	219
126	344·8	1186·6	871·1	·2867	3·49	217
127	345·4	1186·8	870·7	·2889	3·46	215
128	346·0	1186·9	870·2	·2911	3·44	214
129	346·6	1187·1	869·8	·2933	3·41	212
130	347·2	1187·3	869·4	·2955	3·38	211
131	347·8	1187·5	869·0	·2977	3·35	209
132	348·3	1187·6	868·6	·2999	3·33	208
133	348·9	1187·8	868·2	·3020	3·31	206
134	349·5	1188·0	867·8	·3040	3·29	205
135	350·1	1188·2	867·4	·3060	3·27	203
136	350·6	1188·3	867·0	·3080	3·25	202

Total Pressure per square inch.	Temperature.	Total Heat, reckoned from 32° Fahr.	Latent Heat.	Density or Weight of one cubic foot.	Volume of one pound of steam.	Relative Volume, or cubic feet of steam from one cubic foot of water.
lbs.	Fahr.	Fahr.	Fahr.	lb.	cubic feet.	Rel. vol.
137	351·2	1188·5	866·6	·3101	3·22	200
138	351·8	1188·7	866·2	·3121	3·20	199
139	352·4	1188·9	865·8	·3142	3·18	198
140	352·9	1189·0	865·4	·3162	3·16	197
141	353·5	1189·2	865·0	·3184	3·14	195
142	354·0	1189·4	864·6	·3206	3·12	194
143	354·5	1189·6	864·2	·3228	3·10	193
144	355·0	1189·7	863·9	·3250	3·08	192
145	355·6	1189·9	863·5	·3273	3·06	190
146	356·1	1190·0	863·1	·3294	3·04	189
147	356·7	1190·2	862·7	·3315	3·02	188
148	357·2	1190·3	862·3	·3336	3·00	187
149	357·8	1190·5	861·9	·3357	2·98	186
150	358·3	1190·7	861·5	·3377	2·96	184
155	361·0	1191·5	859·7	·3484	2·87	179
160	363·4	1192·2	857·9	·3590	2·79	174
165	366·0	1192·9	856·2	·3695	2·71	169
170	368·2	1193·7	854·5	·3798	2·63	164
175	370·8	1194·4	852·9	·3899	2·56	159
180	372·9	1195·1	851·3	·4009	2·49	155
185	375·3	1195·8	849·6	·4117	2·43	151
190	377·5	1196·5	848·0	·4222	2·37	148
195	379·7	1197·2	846·5	·4327	2·31	144
200	381·7	1197·8	845·0	·4431	2·26	141

From the preceding Table of the properties of steam, it is apparent that the total heat slowly increases with the temperature. It may be well to introduce in this place the results of twenty-eight carefully conducted trials, Table No. 30, by Mr. Josiah Parkes, made in 1838, to test the theory, at that time maintained, that the total heat of steam was the same at all temperatures. Within the limits of Mr. Parkes's trials namely, from 15 lbs. to 60 lbs. total pressure per square inch, the quantity of coal consumed for the evaporation of 20 cubic feet of water varied from 195 to 200 pounds. A cursory inspection of the fifth column of the Table suffices to show generally a moderate increase of consumption with the pressure. The trials were made with an ordinary locomotive boiler. Mr. Parkes's Table is here given without alteration:—

TABLE No. XXX.

SUMMARY OF MR. PARKES'S EXPERIMENTS ON THE PRODUCTION OF STEAM AT DIFFERENT PRESSURES.

Expts.	Pressure.	Temp.	Coals.	Burnt.	Water.	Duration.	
No.	Above Atm. lbs.	Deg. Fah.	Total lbs.	Each exp. lbs.	Evapt. cub. ft.	h.	m.
4	0	212·	800	200	20	10	0
1	5	226·3	199	199	20	9	55
1	10	237·64	202	202	20	10	1
3	1	247·94	585	195	20	9	50
2	20	256·78	396	198	20	10	2
1	25	264·82	204	204	20	10	4
1	30	272·02	200	200	20	10	0
1	35	278·80	203	203	20	9	58
2	40	285·04	404	202	20	9	59
2	45	290·76	408	204	20	10	5
3	50	295·96	615	205	20	10	0
3	55	300·76	624	208	20	9	57
4	60	305·06	840	210	20	10	2

CHAPTER XIII.

FLOW OF STEAM.

It is known that gases and vapours act like liquids in flowing through tubes and orifices. Now, the velocity of flow of liquids is given by the ordinary formula of gravity,

$$V = \sqrt{2\,g\,h}, \text{ or } V = 8\sqrt{h};$$

in which V is the velocity in feet per second; g is the velocity acquired by a body in falling freely from a state of rest, at the end of one second, being 32·2 feet per second; and h is the height in feet through which the body falls. In words, the formula is to the effect, that the velocity acquired in falling through a given height is equal to eight times the square root of the height in feet; the product being the velocity expressed in feet per second. A modification of the same formula is applicable for calculating the flow of gases. But there is this distinction, that whilst, for liquids, the height through which the water falls, to the orifice of flow, can be easily ascertained by measurement,—for gases, it is necessary to ascertain the height by calculation, thus:—The pressure of the gas or vapour is equal to that of a column of the gas of which the weight is equal to the pressure; and if the pressure per square inch be divided by the weight of a prism of the gas, one inch square and one foot high, the quotient is the height in feet of the equivalent column of gas, from which the velocity of flow is to be calculated. The velocity so calculated applies to the discharge of the gas into a vacuum. But, in ordinary circumstances, a counter-pressure exists, being the pressure of the medium into which the gas is discharged; and the value of the counter-pressure is to be deducted from the total pressure, when the difference—the nett pressure—is the pressure from which the head or height of the column is to be calculated. The head is expressed by the formula,

$$h = \frac{p - p'}{d}$$

in which h is the head or height of the column, p and p' are the total pressures per square inch of the gas and the medium into which it flows, and d is the density or weight of a prism of the gas one inch square and one foot high.

The application of the formula for gravity is, however, limited to cases in which the resisting pressure does not exceed about 58 per cent. of the absolute pressure which causes the flow. The flow is neither increased nor diminished by reducing the resisting pressure below about 58 per cent. of the absolute pressure in the boiler. For example, the same weight of steam would flow from a boiler under a total pressure of 100 lbs. per square inch, into steam of 58 lbs. total pressure, as into the atmosphere.* In conformity with these views, according to the "Report on Safety-Valves," taking the pressure of the atmosphere equal to 14·7 lbs. per square inch, and the initial pressure at not less than 25·37 lbs. total, the velocity of discharge into the atmosphere, computed as for the volume of steam of the initial density, through the best form of orifice, is found by employing the coefficient 3·5953 in the formula for gravity: thus

$$V = 3{\cdot}5953\sqrt{h}; \text{ or}$$

$$V = 3{\cdot}5953\sqrt{\frac{p - p'}{d}}.$$

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* For this remarkable discovery it appears that we are chiefly indebted to the experiments made by Mr. R. D. Napier, the results of which were published by him in 1866. For further consideration and analysis of this apparent suspension of the laws of motion, see the "Report on Safety-Valves," presented to the Institution of Engineers and Shipbuilders in Scotland, 1874.

The following are a few examples, computed by means of the formula, of the velocity of efflux of steam of absolute pressures, varying from 25·37 lbs. to 100 lbs. per square inch, into the atmosphere; the velocity being calculated as for steam of the initial density, unexpanded:—

Total Pressure.	Velocity of Efflux.
25·37 lbs. per square inch	863 feet per second
30 " "	867 " "
45 " "	877 " "
60 " "	885 " "
75 " "	891 " "
100 " "	898 " "

It remains to be stated that the outflowing steam, as it approaches and enters the narrowest section of the jet, expands from 1 to 1·624 time the initial volume, and that, therefore, the actual velocities with which the steam, as expanded, passes the throat of the orifice are 1·624 time the velocities computed by the formula.

Velocities thus calculated, in terms of simple pressure and density, are of course greater than are arrived at in practice, as there are sundry hindrances to the flow of steam in steam-engines. There is, however, ample margin, and in well-constructed engines the speed of the actual flow of steam, though much below what it would attain if the flow were free, is, nevertheless, sufficiently rapid for the proper performance of the steam in passing into and passing out of the engine.

To reduce as much as possible the effects of contraction and friction in retarding the flow of steam, it is necessary to observe the following precautions:—1st, to reduce as much as possible the lengths, and increase the sectional areas, of the pipes and passages through which the steam is to pass; 2nd, to avoid sudden changes of direction and of section; 3rd, to obtain the steam as dry as possible.

CHAPTER XIV.

STEAM BOILERS.

Definitions.—The *shell* of a boiler, as the name signifies, is the outer part of iron. It may be spherical, cylindrical, or flat in figure, or a combination of these forms. The *steam-chest*, or *dome*, on the upper side of the boiler, is a reservoir whence the steam is drawn, to supply the engine, by the *steam-pipe*, which is fitted with a *stop-valve*. The *furnace*, or *fireplace*, is the chamber in which the fuel is burnt for the production of heat; when within the shell, as an envelope, it is called the *fire-box*. The *flues*, or conduits for the products of combustion, are either *external* to the shell, or they consist of *internal* cylindrical metal flues of small diameter, about four inches or less, and in numbers. Such circular flues are called *flue-tubes*, and they constitute a *multitubular flue*. The flue-tubes are fixed at the ends into *tube-plates*. The *man-hole* is the entrance to the boiler for inspection, &c. *Mud-holes* are placed at or near the bottom, for the discharge of sediment and for washing out the boiler. The water is supplied by the *feed-apparatus;* its level is indicated by a *float*. The boiler is emptied by the *blow-off cock;* the surface of the water is cleared by the *scum-cock*. *Brine-pumps* may be used instead of *blow-off cocks*, to draw off the brine from marine boilers. *Sediment-collectors* receive the solid impurities in the water. Surplus steam escapes by the *safety-valves*. *Vacuum-valves* admit air into the boiler, when the pressure is less than that of the atmosphere. *Fusible plugs* are inserted in the crown of the furnace, or fireplace, which are melted and give vent to the steam when the pressure and temperature in the boiler become excessive and dangerous. The *pressure-gauge* indicates the pressure. The *water-gauge* shows the level of the water: it may be a *glass tube* or it may be *gauge-cocks.* The boiler is strengthened by *stays,* which may consist of *rods, bolts,* or *gussets.* The boiler is covered with *clothing* or *cleading.* The *firegrate* carries the fuel, and consists of *fire-bars, furnace-bars,* or *grate-bars,* supported by *cross bearers* or *bar-frames.* The *mouthpiece* is the entrance to the furnace, and rests on the *deadplate,* which is the sole of the entrance; the *fire-door* is fitted to and hung to the mouthpiece or to the *furnace-front,* which is applied to ordinary flue boilers, being of cast iron, fastened to the boiler.

The waggon-boiler of Watt, which has already been illustrated and described (pages 52—55), was an exceedingly effective boiler, well suited for steam of low pressures not exceeding 7 lbs. per square inch above the atmosphere. In form it is, moreover, essentially weak, since the centrifugal pressure of the steam, equal in all directions, is very unequally resisted by the variously formed parts of the waggon-boiler. The cylindrical form is the only permanent or self-maintaining form; and for any deviation from the circular section, stay rods, or brackets, are necessarily applied to counteract the constant tendency of an irregular surface to expand into a cylindrical or a globular form.

The waggon-boiler, therefore, has gone down before the advancing requirement for steam of higher pressure, and has become nearly extinct. The cylindro-spherical or egg-end boiler was introduced to meet the requirements for higher pressure. Being simply a cylinder with spherical ends, the use of stays was avoided, as great strength and permanency of form were obtained without any other metal than the shell of the boiler itself. It is laid with its axis nearly horizontal, and below it at one end is placed the fire; and the whole is enclosed in brick, by which also are the flues which conduct the flame and hot gases round the boiler. The flame traverses the bottom of the boiler, beating directly upon its under horizontal surface, till it reaches the end farthest from the fire. The flame and hot air then, in some examples, return along one side of the cylinder, conducted by a flue, and, passing round in front of the end which is over the fire, traverses the other side towards the chimney, which it enters after having thus traversed the length of the boiler three times, and applied its heat successively to every point of the cylinder that is covered with water. This boiler is useful where economy of room is not important; but it contains much water, requires much heat to raise its temperature after being cooled at night, and is very bulky. It is employed mostly at collieries.

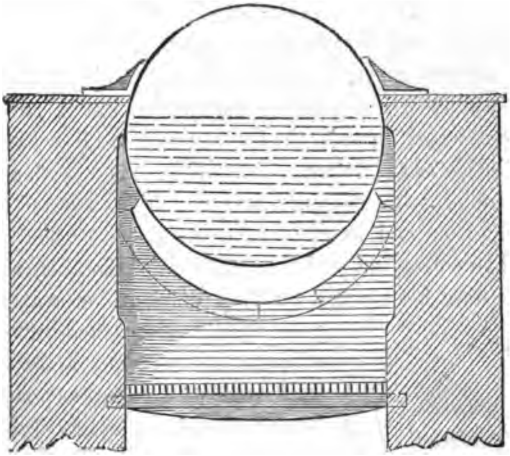


Fig. 99.—Cylindrical Boiler. Section.

The spherical boiler, which antedates the waggon-boiler and the cylindrical boiler, need only be mentioned now; and these three boilers may be denominated the simple boilers, But some hundreds of boilers have been invented for different purposes, almost all of them to save either bulk, weight, or fuel. For these purposes, one great object of improvements in boilers has been to increase as much as possible the extent of heating surface without increasing the general dimensions. Boulton and Watt inserted a longitudinal flue in the middle of their waggon-boiler, so that after the flame had passed along the bottom of the boiler to the farther end, it returned through the flue in the middle of the water to the front, and then made an entire circuit of the outside of the boiler before entering the chimney. Internal flues have similarly been placed in egg-ended cylindrical boilers.

Still more to centralise and economize the heat, which was radiated more or less from the mass of brickwork surrounding the external furnace, the furnace with the fire was placed in the inside of the boiler. Trevithick constructed a cylindrical boiler with flat ends, into which he inserted a large flue-tube from end to end; in one end of the flue-tube he erected the fireplace, and thus the first of the heat, which is also the most intense and the most efficient for evaporation, was wholly discharged upon the evaporating surface of the boiler. The type of boiler thus originated by Trevithick—a cylindrical boiler with flat ends and a single flue—is known as the Cornish boiler, represented by Fig. 100, and is exclusively employed for the service of pumping-engines in Cornwall, and similar engines elsewhere; it is also employed for miscellaneous service on land. The Cornish boiler is made of various dimensions, varying from 5 ft. to 7 ft. 6 in. in diameter and from 20 ft. to 30 ft. in length. The fireplaces and inside flues are made as one tube from end to end, from 3 ft. to 4 ft. in diameter. The fireplace is within one end

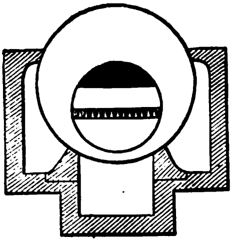


Fig. 100.—Cornish Boiler. Section through Furnace.

of the flue, where the grate is constructed of the full width of the flue, and with a length usually about one and a half times the width. The flame is, or ought to be, conducted from the flue under the boiler, and thence by the side flues. The boiler is set in brickwork, shown in section in the figures. The Cornish boilers at the East London Waterworks are, for the 90-in. cylinder pumping-engine, three in number, 6 ft. 6 in. in diameter, 34 ft. long, with a 4 ft. flue and grates 6 ft. long. They consume 4·2 lbs. of small Welsh coal per square foot of grate per hour, and they evaporate 50 cubic feet of water per hour, or 10 lbs. from 102° Fah. per pound of coal, or two-thirds of a cubic foot per square foot of grate per hour. The working pressure of steam is 35 lbs. above the atmosphere.

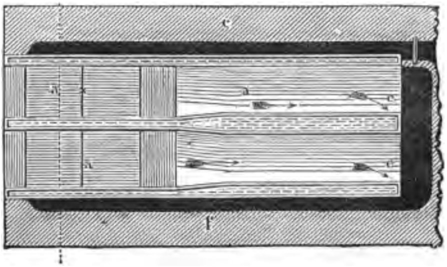


Fig. 101. Lancashire Boiler. Plan.

The Lancashire boiler, Figs. 101 and 102, was introduced subsequently to the Cornish boilers, and, as its name implies, it is employed almost exclusively in Lancashire and the north. It consists, like the Cornish boiler, of a cylindrical shell with flat ends, but has two thorough flues, from end to end, in which two fireplaces are arranged; necessarily less in width individually than the

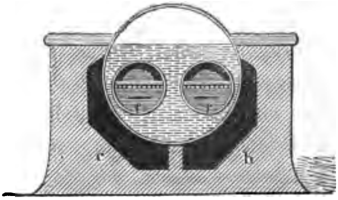


Fig. 102.—Lancashire Boiler. Section.

single fireplace of the Cornish boiler, though together of greater width, and therefore affording a greater breadth of fire-room. The Lancashire or double-flue boiler is made from 7 ft. to 8 ft. in diameter, and in exceptional instances 9 ft. or 10 ft. in diameter, with a length of from 28 ft. to 32 ft. The flue-tubes vary, according to the diameter of the boilers, from 2 ft. 3 in. to 3 ft. 9 in. The most common diameter of shell is 7 ft., with 9 ft. 9 in. flues.

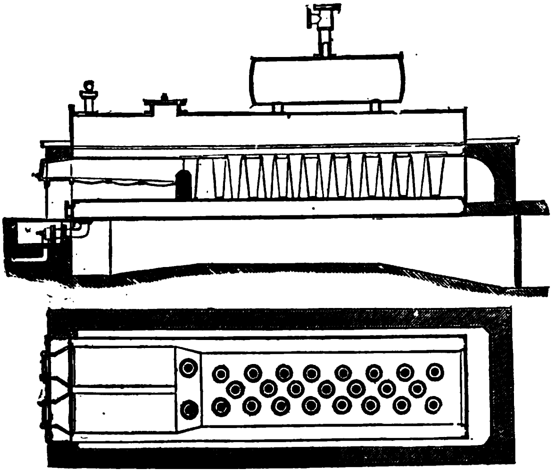


Fig. 103.—The Galloway Steam-Boiler.

The Galloway boiler, Fig. 103, is the third form of flue-boiler in extensive use. It is made with a large oval flue within the boiler, having a number of vertical conical water-passages uniting the top and bottom of the flue, so that a free circulation of water is maintained, and a considerable addition to the heating surface is effected. There are two furnaces placed in the short flues in front, as in the Lancashire boiler, which are united at the inner ends, where they are connected to the single oval flue.

In all of these horizontal-flue boilers, the products of combustion pass direct from the fireplaces through the internal flues, and pass, or ought to pass, under the boiler to the front, where the current is split, and return by the side flues to the far end, whence they escape to the chimney. On this system the length of the boiler is traversed three times, making a length of current, in contact with a boiler 30 ft. long, equal to 90 ft. The two fireplaces of the Lancashire and the Galloway boilers are charged with fuel alternately, from which practice two good results follow: first, that the general temperature of the products of combustion is more nearly uniform than when they proceed from a single fireplace; and, second, that the process of combustion is rendered more nearly complete by the intermixture of the fresh gases driven off from coal newly charged into one furnace with the hotter and simpler gases delivered from the other furnace in which the fuel has attained to a state of incandescence. It may be remarked, further, that the upright water-tubes in the flue of the Galloway boiler break up and intermingle the gaseous products from the two fireplaces in their passage through the oval flue.

The French boiler (*chaudière à bouilleurs*)—a boiler in common use in France—known also as the elephant boiler (Fig. 104), consists of a plain cylindrical body and one or more "boilers" (*bouilleurs*), or large tubes of smaller diameter than the body of the boiler; these are placed near the furnace, and connected to the body by tubes. In this design of boiler the circulation of the water and steam requires to be specially provided for, and this is secured by introducing the feed-water, through the connecting tubes at one end, to the lower boilers, the effect of which is that the steam formed in them escapes and ascends by the connecting tubes at the other end. The upper part of the lower boilers are protected

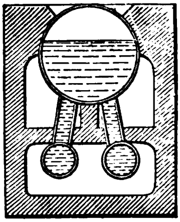


Fig. 104.—Elephant Boiler. Section.

by firebricks against the heat, which might otherwise overheat them, seeing that there is always a certain accumulation of steam in them. The French boiler has never made a footing in England.

Though the inside flue and furnace are generally acknowledged to act superiorly to the ordinary under furnace applied to the egg-end cylindrical boiler, the egg-end boiler with its external fire is, nevertheless, in extensive use. It is a favourite at collieries and elsewhere, where skilled attendance is scarce; it holds a large and compact mass of water, and admits of considerable fluctuations of level of water without incurring the danger of overheating by uncovering the portions of the boiler exposed to the heat of the flues. In these respects the under-fired flueless boiler does not demand the same degree of attention and management as flued boilers, which hold a smaller body of water, and are more liable to accident by collapse of the flue by overheating, arising from lowness of water. The danger of accident by such collapse is, however, entirely obviated by the application of stiffening rings of angle-iron to the outside of the flue-tube, at short intervals apart.

Horse-power and Evaporative Performance of Flue-Boilers.

A Lancashire boiler, 6½ ft. in diameter, 24 ft. in length, evaporates, in ordinary, 50 cubic feet of water per hour. Taking the product of the diameter and the length as a measure of power, it is $6\frac{1}{2} \times 24 = 156$ square feet, or 3·12 square feet of horizontal section per cubic foot of water per hour. The heating surface is 610 square feet, or 12·2 square feet per cubic foot. The grate-area is, say, 25 square feet, or ½ square foot per cubic foot of water per hour.

The nominal horse-power of a flue boiler, either Cornish or Lancashire, is usually reckoned at the rate of from 5½ to 6 square feet of horizontal section, 15 square feet of heating surface, and one square foot of grate-area per nominal horse-power. An evaporation of one cubic foot of water per hour has also been reckoned as the measure of a nominal horse-power by evaporation. These measures of nominal horse-power are not quite consistent with each other, but the whole system of measurement is in its nature elastic. It is known, besides, that a boiler of the above dimensions can evaporate, under favourable circumstances, more than 50 cubic feet per hour. It is known, further, that the actual or indicated horse-power realised from the steam by the instrumentality of the engine may amount to from two to three or even four times the nominal power.

The evaporative efficiency of such a boiler varies very much according to the care and skill with which it is fired, as well as the quality of the fuel. Eight pounds of water supplied at 62° Fah. may be evaporated per pound of coal; or only 7 pounds may be evaporated. On the contrary, under the best management, not only may the evaporative performance of such a boiler be increased to 80 cubic feet of water per hour, but 9 pounds of water supplied at 62° Fah. may be evaporated by one pound of coal. The quantity of coal consumed varies from 16 to 20 pounds per square foot of grate per hour.

Multitubular Boilers.

A form of boiler with internal flues of a mixed character, was introduced by the late Sir William Fairbairn, having the double flue in conjunction with the multitubular system, and known as the multitubular boiler. Those which were made for the Saltaire Works, near Bradford, had the shell 24 ft. long and 7 ft. in diameter. The fire, generated in the fire-tubes, which are 2 ft. 6 in. in diameter, passes into the mixing-chamber, that the air may be mixed with the flame and smoke, for the sake of perfecting the combustion; thence the products of combustion pass onwards through 109 small tubes, 3 inches in diameter, within and at the farther end of the boiler, and descend into the brickwork flues beneath the boiler.

A compact form of multitubular boiler is constructed by Messrs. Cater and Walker, London, resembling in general arrangement the multitubular marine boiler. The boiler is in general section rectangular, and the lower part is occupied by the furnace, from which the products of combustion pass into a chamber at the back, and thence return through a multitubular flue over the furnace into a smoke-box, from which they pass into the chimney. This form of boiler is in considerable use in London, where space is limited, and compactness essential.

But the multitubular boiler, for stationary purposes, is most commonly upright in its arrangement; that is, the shell, which is cylindrical, is placed with its axis vertically. Within the lower part is the furnace and ash-pit, surrounded by water; and immediately over the furnace the flue-tubes are placed, through which the products of combustion pass direct from the furnace and into the chimney. The upright is the most compact of all boilers.

It is usually reckoned that $\frac{3}{4}$ square foot of grate, and 25 square feet of heating surface, are the proper allowances per nominal horse-power for multitubular boilers. These allowances are larger than for ordinary flue-boilers, because the heating surface in the gross is considered to be less efficient for evaporation, by the square foot, than that of Cornish or Lancashire boilers. The direct upward draft, though it quickens combustion and excites a high temperature, is wasteful, inasmuch as the heat is too rapidly conveyed, and much of it is carried away into the chimney. Expedients for detaining or deflecting the upward current are, therefore, found to operate with advantage in economizing fuel, by causing the absorption of a greater quantity of the heat produced. The same useful effect is obtained by providing means for the regular and rapid circulation of the water within the boiler, causing it swiftly to traverse the heated plates, through which the heat is transmitted; and then by disengaging and removing the steam as it is formed, maintaining a stratum of comparatively "solid" or free water in contact with the metal, for the more rapid absorption of the heat.

The "Field" boiler, the invention of Mr. Edward Field is so constructed as to effect the desiderated circulation to a remarkable degree. An upright boiler on this system is shown, Fig. 105. A number of small tubes, 2½ inches in diameter, are let into and through the roof of the furnace, to which they are fixed, and from which they depend, into the atmosphere of the furnace, where they are exposed to the full force of the heat. Their lower ends are closed, and their upper ends are open to the interior of the boiler, from which they are kept full of water. A tube of smaller diameter is inserted into each of the pendant tubes, reaching nearly to, but not touching, the bottom, whilst the upper end of the smaller tube rises above the orifice of the outer tube. By this means the steam which is formed on the surface of the outer tube rises into the annular steam space between the tubes, and a fresh supply

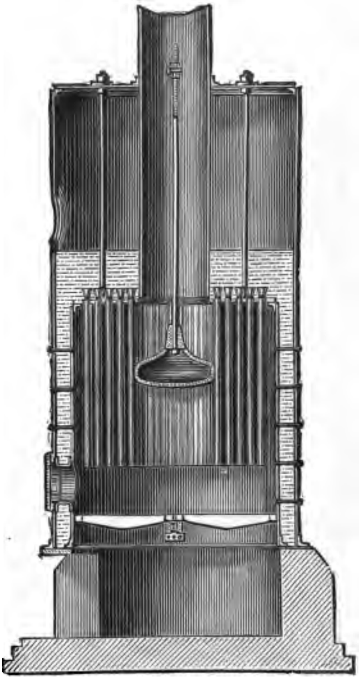


Fig. 105.—The Field Boiler.

of water is conducted through the inner tube and delivered into the outer tube at the bottom, through which it rises to take the place of the displaced steam. Thus a circulation of extreme rapidity is set up, and so effective is it understood to be for promoting evaporation that, it is said, six square feet of the heating surface of the Field boiler are capable of evaporating one cubic foot of water per hour. These circulating tubes have also been applied to the flues of ordinary boilers. They are extensively used in the construction of fire-engines.

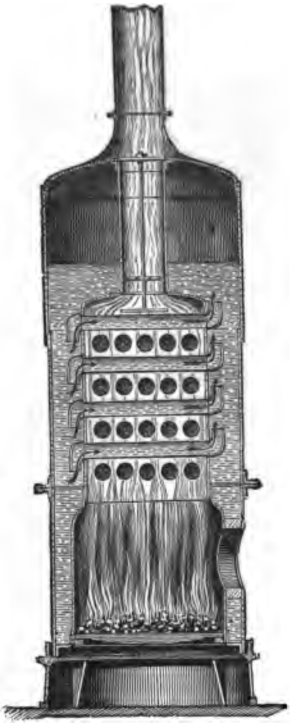


Fig. 106. The Nozzle-Boiler.

The "nozzle-boiler," constructed by the Reading Iron Works, Fig. 106, consists of two parts, — the fire-box, which is circular, and the tube-chamber, which is square in plan, and is traversed by rows of tubes, 2¾ inches in diameter outside, set horizontally at right angles to each other. At the ends of the tubes, nozzles or circulators of cast iron are fixed, the nozzles at one end being turned downwards, and those at the other upwards, so that the steam, as it is generated in the tubes, rushes out through the upturned nozzles, and water rushes in to supply its place, through the downturned nozzles. A prompt circulation of water and steam, conducing to economy of fuel and quick production of steam, is thus effected. According to the results of trials made by the manufacturers with a five-horse-power nozzle-boiler, with 4 square feet of grate-area and 72 square feet of heating surface, upwards of 11 cubic feet of water was evaporated from 65° Fahr. per hour, with a consumption of 88 lbs. of coal per hour, showing an evaporation of 8 lbs. of water at 65° Fahr. per pound of fuel—equivalent to 9·2 lbs. of water at 212° Fahr. per pound of coal. The performance of the nozzle-boiler confirms the advantages of two things—the horizontal tube-surface and rapid circulation within the boiler.

There are other kinds of vertical boilers which have been designed, in different ways, for the purpose of increasing the evaporative power and efficiency as compared with ordinary multitubular vertical boilers.

Strength of Steam-Boilers.

The strength of boilers is dependent upon the tensile strength of the material of which they are constructed. The following are the average ultimate tensile strengths of boiler-plate of different kinds,—that is to say, the weights required to tear the material asunder per square inch of section :—

Yorkshire iron plates, best quality	25 tons
Staffordshire " "	20 "
American " "	31 "
" " ordinary	27 "
Cast-steel plates	40 "

At the joinings of boiler-plates the strength is less than on the untouched body of the plate. Taking the tensile strength of the solid plate, of any material, at 100, the relative strengths of the different kinds of joints of boiler-plates are as follows :—

The solid plate	100
Scarf-welded joint	100
Double-riveted double-welt joint	80
Double-riveted lap-joint	72

Lap-welded joint	66
Double-riveted single-welt joint	65
Single-riveted lap-joint	60

These proportions may be taken as correct for plates not exceeding ⅜ inch in thickness. For thicker plates the relative strengths are smaller, and, in some cases, thicker plates are positively weaker at joints—particularly lap-joints—than thinner plates.

The safe or "working" strength, or the limit within which the plate-work of boilers may be strained without incurring the risk of being overstrained or crippled, is usually reckoned at from one-fifth to one-sixth of the ultimate or breaking strength.

To calculate the safe strength of a cylindrical boiler, take a boiler 6 feet in diameter, made of Staffordshire plates ⅜ in. thick. The united thickness of two opposite sides of the boiler is $\frac{3}{8} \times 2 = \frac{3}{4}$ inch, and there is ¾ square inch of sectional area of metal to resist the strain on one inch length of the boiler. Now the breaking strength of Staffordshire plate is 20 tons per square inch, equivalent to 15 tons on ¾ square inch; it follows that the breaking strength of the solid plate of the boiler is 15 tons per inch run. To find what pressure of steam will produce this ultimate stress of 15 tons, or 33,600 lbs., it is to be divided by the interior diameter of the boiler in inches: thus—

$$33{,}600 \div 72 = 467 \text{ lbs. per square inch}$$

is the pressure of steam which would exert a pressure equal to the breaking strength of the solid metal. Taking one-sixth of this ultimate pressure for the safe working pressure,

$$467 \div 6 = 78 \text{ lbs. per square inch}$$

is the limit of safe working pressure. But, inasmuch as the strength of a boiler, as of any other structure, is simply that of the weakest part, the nature of the joints fixes the real limit of the safe working pressure, and 78 lbs. per square inch is therefore to be reduced in the ratio of the relative strengths, as follows :—

For a Boiler of Staffordshire Plate, 6 ft. in diameter, $\frac{3}{8}$ths inch thick.

The solid plate	78	lbs. per	square inch.
Scarf-welded joint . . .	78	,,	,,
Double-riveted double-welded joint	62	,,	,,
Double-riveted lap-joint . .	56	,,	,,
Lap-welded joint	52	,,	,,
Double-riveted single-welded joint	51	,,	,,
Single-riveted lap-joint . .	47	,,	,,

Ordinary Working Pressure in Steam Boilers.

Very few boilers are worked at pressures less than 15 lbs. per square inch above the atmosphere. About half the stationary boilers in Lancashire and Yorkshire are worked at pressures varying from 45 lbs. to 60 lbs. per square inch, and several are worked at pressures of from 60 lbs. to 75 lbs. per square inch above the atmosphere.

The boilers of portable engines are worked at 80 lbs. per square inch above the atmosphere, and one manufacturer works at 120 lbs. per square inch.

CHAPTER XV.

SECTIONAL STEAM-BOILERS.

SECTIONAL boilers—boilers which are constructed of a number of small parts, semi-independent, united together—were designed and tried many years ago. They consist usually of tubes of small diameter, 12 inches or less, containing water and steam, and surrounded by the fire and heat from the furnace. The earliest of such "water-tube" boilers appear to have been that of Blakey, in 1756, Fig. 33, page 41, *ante.* The chief motive for the introduction of sectional boilers, in recent years, has been the increasing use of steam of very high pressure, for stationary purposes, of from 50 lbs. to 100 lbs. per square inch; taken in connection with the frequency of explosions of steam-boilers of the ordinary large-shell forms. By the substitution of multiples of a small unit—a tube—for one large unit—a shell—it is considered that failures by explosions are less likely to happen, and that the consequences of explosions, when they do happen, are much less dangerous and destructive.

Mr. Martin Benson introduced his high-pressure sectional steam-boiler in England in 1859-61. It had been at work in America since 1857. It consisted entirely of wrought-iron tubes, arranged in a series of horizontal rows over the fire, of which the lower tubes were 1¼ inch in diameter for the lowest third of the height of the boiler, the next third were 1½ inch, and the uppermost third 1¾ inch. The furnace was 6 feet square in plan, and the tubes were connected at the ends by semicircular unions, so that continuous currents of water and steam passed from the lower ends to the upper ends, traversing the furnace several times horizontally. The circulation of the water was effected mechanically by means of a circulating pump; thus, in a simple and easy manner, eight or ten times the quantity of water was supplied to and forced through the boiler, that was required for generating steam; the efficiency of the heating surface was maintained, the steam cleared away when formed, and incrustation, to a great extent, prevented from lodging on the insides of the tubes. The tubes were only ⅛ inch in thickness. The regular working pressure was from 150 lbs. to 200 lbs. per square inch. With 460 square feet of heating surface, about 60 cubic feet of water was evaporated per hour, of which 5½ lbs. was evaporated per pound of coal—Staffordshire slack. The speciality of Benson's boiler was the application of mechanical power for circulating the water through the boiler. Though the tubes were easily renewed when required, it seems to have been felt that a dependence upon special mechanical means for effecting the circulation of the water in the boiler was objectionable, and inventors of sectional boilers have sought, by other arrangements, to effect the necessary circulation of the water by a self-acting movement. The best known sectional boiler is probably that of Messrs. Howard, of Bedford, of which a sectional elevation is given in Fig. 107. The boiler is composed of wrought-iron tubes, 9 in. in diameter externally, these tubes being connected

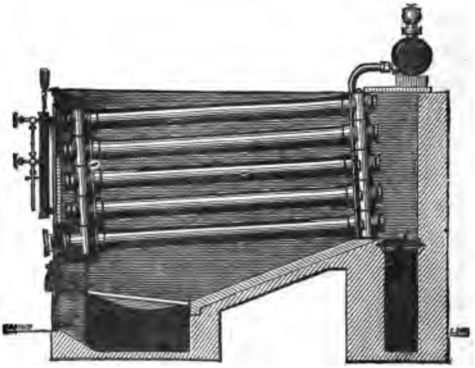


Fig. 107. Howard's Sectional Boiler.

together in groups, and being placed at a slight inclination; the tubes of each group lie one over the other, and they are connected together at both ends. Each tube has a cast-iron cap or chamber fixed to it at each end, the chambers at each end being united by a through bolt from top to bottom. The chambers are provided with doors, one opposite the end of each tube, thus affording facilities for inspecting the tubes. In this boiler there is neither welding, screwing, nor riveting, whilst the whole of the interior is readily exposed to view and cleaned out. The whole is set in and covered in by brickwork, with a fire-grate under the lower ends of the tubes. The steam is led off from the higher ends of the tubes into a condensing pipe or steam-drum. By means of horizontal fire-brick partitions, the current of flame and heated gases from the furnace is conducted to the back of the furnace, where it rises into the middle portion of the boiler, and is conducted horizontally towards the front and again returned through the upper part of the chamber towards the back, and is then conducted by a downward flue to the chimney. The uppermost tubes in the collection contain only steam, which, being exposed to the passing gases, is dried and, to some extent, superheated before it passes away to the drum.

A 60 H.P. Howard boiler consists of six sections of six tubes each—in all 36 tubes. Each tube is 12 feet long, 9 inches in diameter externally, and $\frac{5}{16}$ inch thick. The tubes are tested, as plain tubes, to a pressure of from 500 lbs. to 700 lbs. per square inch; and the boiler is tested, when put together, to a pressure of 300 lbs. per square inch. With 35 square feet of grate area, the boiler contains 825 square feet of water-heating surface and 305 square feet of steam-superheating surface:—together, 1,130 square feet. The boiler is capable of evaporating 60 cubic feet of water, and, according to the results of trials carefully made at Barrow-in-Furness, 9½ lbs. of water was evaporated per pound of "duff," or unscreened small coal.

CHAPTER XVI.

STEAM-ENGINES.

Definitions.—The steam is led to the engine through the *steam-pipe* from the boiler, in which the *stop-valve* is placed; also the *throttle-valve*, or regulator, for adjusting the supply of steam; the supply being controlled by the *governor*. The steam is admitted into the *cylinder*, where it acts on the *piston*, through *steam-passages*, *steam-ways*, or *nozzles*, the entrances to which are called the *ports*, opened and closed by *induction* and *eduction* valves, or by a single *slide-valve*, in the *valve-chest*. The *waste steam* is discharged from the cylinder, through the *exhaust pipe*, into the *condenser*, where it is condensed; or into the atmosphere, if there be not a condenser, by a *blast-pipe* in locomotives. The *cylinder-cover* has a *stuffing-box* to pass the *piston-rod*. A *grease-cock*, or *lubricator*, is connected to the cylinder, or to one of its covers, for the lubrication of the piston. An *escape-valve*, held by a spring, may be placed at each end of the cylinder, or *blow-through* or *cylinder-cocks*, for the escape of water collected in the cylinder. The cylinder is sometimes cased in a *jacket* filled with steam; and the cylinder and the jacket are covered with *clothing* or *cleading*. In land engines, the *injection-water* is supplied from the *cold well* surrounding the condenser, which is filled by the *cold-water pumps*. In the *surface-condenser*, the steam is condensed within or without tubes or other passages, cooled by water on the other side. The *blow-through* valves connect the cylinder with the condenser and the *snifting valve,* through which air is driven by steam from the cylinder and condenser before the engine begins to work. The pressure in the condenser is measured by the *vacuum-gauge.* Residual steam, air, and water are exhausted from the condenser by the *air-pump,* and discharged into the *hot well,* from which the boiler is supplied with water. The *crosshead* of the piston-rod is guided by a *parallel-motion,* to move in a straight line. The parallel-motion may consist of *radius rods* or of *guide bars.* In *oscillating engines,* the cylinders oscillate on *trunnions.* The reciprocations of the piston are either transmitted through a *beam* and a *connecting-rod* to the *crank* and the *crank-shaft,* for double-acting *rotation engines;* or there may not be a beam, and the crosshead is pinned direct to the connecting rod, forming a *direct-action engine.* The *fly-wheel* on the crank-shaft equalises the motion. The mechanism to work the valves is the *valve-gear* or *valve-motion.*

A *pair of engines* are duplicate engines working together on the same shaft. A *compound engine* has two or three *compound* or *compounded cylinders* working to the same shaft, the steam from the first cylinder being exhausted into the second, or into the second and third cylinders, and thence to the condenser. An intermediate *receiver,* or *reservoir,* in some compound engines receives and stores the steam exhausted from the first cylinder, to be admitted to the second cylinder.

Classification of Steam-engines.—Irrespective of the uses to which engines are applied, they are distinguished into the two great classes, *condensing engines* and *non-condensing engines;* the former exhausting the used steam into an artificial atmosphere of very low pressure; the latter exhausting the steam into the natural atmosphere, of which the resisting pressure is 14·7 lbs. per square inch. The condensing engine is more efficient in the production of power from fuel than the non-condensing engine; but this has the advantage of greater simplicity and comparative fewness of parts.

There is another classification, based on the uses to which engines are applied: 1st, *stationary engines*, placed in permanent situations, for driving factory machinery, pumping water, &c.; 2nd, *portable engines* placed on wheels, or transportable from one place to another, for temporary service as stationary engines; 3rd, *traction-engines*, for self-movement and for drawing loads on common roads; 4th, *locomotive engines*, for drawing loaded carriages and waggons on railways; 5th, *marine engines*, for propelling vessels on water. The first three classes are those to which attention will be directed in the following pages.

It may be added that steam power is applied in many special forms, as for driving piles, for steam-hammers, steam-pumps, &c.

CHAPTER XVII.

THE DISTRIBUTION AND ACTION OF STEAM IN THE CYLINDER OF STEAM-ENGINES.

In the cylinder of the steam-engine the force of steam is exerted for the performance of work. Steam is conducted directly from the boiler in the condition of maximum density for the pressure and temperature at which it is generated, and delivered to the cylinder. Steam operates in the cylinder in a twofold manner. First, it is admitted, with a greater or less degree of freedom, from the boiler into the cylinder, during a portion of the stroke of the piston, following the piston, and exerting pressure upon it. When the communication from the boiler to the cylinder is cut off, and the supply of steam thus arrested, the quantity of steam enclosed within the cylinder continues, though isolated, to press upon the piston, and it follows and acts on it to the end of the stroke, or at least so far towards the end of the stroke as the steam continues to be shut up in the cylinder.

Here there is a twofold action. First the steam is passively pushed into the cylinder, as if it were an elastic block or a liquid, being merely a medium for the transmission of the elastic force or pressure, originating in the boiler, to the piston; other steam being at the same time generated and supplying the place of the steam so pushed out. Secondly, it is "worked expansively" upon the piston, whilst it is shut up with it. The energy of the steam, or, strictly speaking, that of the equivalent quantity of steam generated in the boiler, is in part utilised in following the piston, direct from the boiler, and is further utilised in virtue of the inherent elasticity of the isolated steam in the cylinder. The whole process is essentially one of expansive action, as the steam admitted direct from the boiler flows into the cylinder in virtue of the expansive force of the steam already generated and being generated, the boiler constituting the fulcrum or basis; then the process is continued on a more limited scale within the cylinder, after the steam is cut off, the steam continuing, in virtue of its own elastic force, its expansive action against the piston, when the end of the cylinder constitutes the fulcrum. For the sake of easy reference, the work done in the cylinder during the admission of steam from the boiler will be ascribed to and assumed to be performed by the steam itself actually admitted.

The difference of the conditions of the pressure or elastic force during the two periods, that of admission and that of expansion, is usually made apparent in the indications of the internal pressure in the cylinder, supplied by the indicator, by means of which the pressure throughout the stroke is observed and registered. But in certain conditions the distinction disappears, and the steady uniform pressure with which the entering steam should take its place in the cylinder merges frequently in the descending pressure characteristic of simply expanding steam. This descending pressure, when indicated while yet the communication between the boiler and the cylinder is open, is the result of what is expressively called a "wire-drawing" of the steam, the flow of steam into the cylinder being partially arrested at the "port," or entrance, by the valve or slide when nearly closed, and the current being thus "wire-drawn" into steam of reduced density and pressure.

But the steam having been got into the cylinder, and having done its appointed work, is to be got out again; and its discharge should be completed by the time the piston has completed the stroke. It is discharged either into the natural atmosphere, opposing a resistance equal to 14·7 lbs. per square inch, or, in round numbers, 15 lbs. per square inch; or into the artificial atmosphere of the condenser, opposing a resistance of about 1 lb. per square inch, less or more, according to the excellence of the means of condensation. The piston of an engine, in fact, works between two pressures, and continues in motion, or has a tendency to do so, as long as the pressure in the boiler is greater than that in the condenser, or, more exactly, in the exhaust passage; and when steam is very greatly expanded in a condensing engine, a low pressure in the condenser is no less necessary than a high pressure in the boiler. If all losses and difficulties incidental to, and perhaps in some degree inseparable from, the use of steam of very high pressure be neglected, then it must be maintained that the highest pressure in the boiler, coupled with the lowest pressure in the condenser, would give the highest duty for a given quantity of heat, provided the steam is expanded in the cylinder from the greater pressure down to, or nearly down to, the lower pressure.

The term "vacuum," it may be remarked, is liable to a double interpretation, signifying either the absolute pressure in the condenser or the difference between this and the atmospheric pressure. Now, in questions affecting the quantity of work of steam and its efficiency in the steam-engine, there are the total pressures respectively in the two separate vessels which require to be considered; that is to say, the initial pressure in the cylinder, and the total pressure in the condenser, into which the exhausted steam is propelled by the superior pressure on the other face of the piston. If the pressure of the atmosphere were 10 lbs. or 30 lbs. in place of 14·7 lbs. per square inch, as it is, it would not at all affect the action of a condensing engine further than slightly diminishing or increasing the force required to work the air-pump, and causing a greater or less weight to be placed upon the safety-valve in order to obtain the same total pressure in the boiler. When the mercury in an ordinary barometer is observed to stand at a height of 30 inches, and the mercury in another tube communicating with the condenser of a steam-engine at a height of 5 inches, instead of describing the conditions of the case as representing a vacuum of 25 inches of mercury, it would afford a clearer conception of the matter to consider that the total pressure in the condenser is equal to 5 inches of mercury, while the total pressure in the boiler is equal to 30 inches of mercury plus the load on the safety-valve. In short, the operations of a condensing engine are practically independent of the incidental variations of atmospheric pressure.

Again, the operations of a non-condensing engine, exhausting into the atmosphere, are referable to the atmospheric pressure, as it affords the datum or base-line to which the expansive and exhaust pressures should be approximated, and below which the former should not, and the latter cannot, be extended. It is usual, therefore, in dealing with non-condensing engines, to designate the pressure of steam by the difference or excess of its pressure above that of the atmosphere—namely, 14·7 lbs. absolute pressure per square inch; this absolute pressure being adopted for the zero of the non-condensing scale. The round number, 15 lbs., is occasionally assumed.

In describing the cycle of events known as the "distribution," or the ordering of the steam admitted to, and subsequently discharged from, the cylinder, it should be noted, by way of recapitulation—speaking of engines as ordinarily formed—that with the cylinder is associated the valve-chest, into which the steam from the boiler enters previously to its passing into the cylinder—an anteroom where the steam waits in readiness to enter the cylinder when admitted. The form and position of the chest or chamber varies indefinitely with the design of the engine. From this chest three passages are formed, one leading to each end of the cylinder, and the third passage leading to the condenser, or to the atmosphere, or otherwise, for the exit of the steam from the cylinder. The orifices of these three passages, or thoroughfares, are known as ports, and are usually brought together and placed parallel, terminating in a flat surface on the side of the cylinder on which the valve reciprocates. The function of the valve is to distribute the steam, for which purpose it is impressed with a simple reciprocating motion, by which it alternately covers and uncovers each port leading to the cylinder, admitting the steam from the chest, suppressing or cutting it off, and ultimately releasing it from the cylinder by opening a means of exit by the third port already mentioned. The reciprocating motion of the valve is derived from an eccentric, in the simpler forms of mechanism fixed on the driving axle, and revolving with it. The linear motion derived to the valve from the eccentric is, on a smaller scale, exactly similar to that of the piston in connection with the crank

That the steam may gain admission to the interior of the cylinder at the commencement of each stroke, the eccentric is so set on the axle, in advance of the crank, as to have the valve moved sufficiently aside at that juncture that the steam port may be uncovered by a small amount known as "lead" at the beginning of the stroke. When the piston has described a portion of the stroke, the valve returns in obedience to the return of the eccentric, and closes the port, thereby shutting off the further supply of steam to the cylinder behind the advancing piston, and confining what has been admitted during an additional portion of the stroke. As the valve continues in its retrograde motion, it uncovers the steam port on the inside, while the piston is still some distance from the end of the stroke, and opens the way out of the cylinder for the steam within, from which accordingly it emerges, and rushes into the condenser or the atmosphere. This external communication continues open, not only to the end of the "steam-stroke," through which the course of the piston has been traced, but also during the greater part of the "return-stroke," while the steam from the valve-chest acts on the other face of the piston. Shortly before the completion of the return-stroke, the valve, in the regular course of the motion prescribed for it by the eccentric, closes the port to the atmosphere, and, finally, at a very small distance from the end of the return-stroke the port is again opened, and the valve obtains the necessary lead in timely preparation for the entrance of steam from the valve-chest before the commencement of the next steam-stroke, and the development of the full steam-pressure on the piston for another cycle of duty.

The periodical and contemporaneous operations of the piston, the valve, and the steam, just described, for one end of the cylinder and one face of the piston, take place independently for the other face of the piston; so that two performances are proceeding together in one cylinder, and the engine is thence denominated double-acting. Four distinct events take place in consecutive order with respect to each end of the cylinder: first, the admission of the steam at, or just before, the beginning of the stroke; second, the suppression of the steam; third, the release or exhaust of the steam; and, finally, the lock-up, or compression, of the exhaust steam, prior to the opening of the port for admission. These four events together constitute the "distribution" for the cylinder; and their durations, measured in parts of the stroke, are the "periods of the distribution." By aid of the indicator, which, as its name implies, is a sort of stethoscope for the observation of what transpires within the cylinder—a simple instrument for receiving and registering the tension of the steam—a minute and accurate picture of the operations within is transferred by pencil to paper, affording valuable and, indeed, indispensable data for the measurement of the power and efficiency of the steam in the cylinder.

But, before proceeding with this part of the inquiry, the movement of the piston relative to that of the crank, as well as the movement and action of the slide-valve in its relation to that of the piston, had better be explained by the process of geometrical illustration.

Geometrical Illustration of the Movement of the Piston relative to that of the Crank.

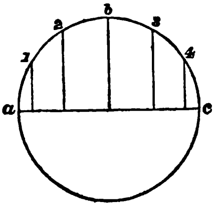


Fig. 108.

The piston acts upon and keeps pace with the crank for every stroke, through the medium of the connecting-rod, and it will have been seen that the varying angularity of the connecting-rod influences the movement of the piston in such a manner that the piston moves more slowly during one half of the stroke—that which is next the crank—than during the other. With an indefinitely long connecting-rod, of which the angularity is inconsiderable, the relation of the motion of the crank and the piston is represented by the annexed diagram, in which *a c* is the stroke of the piston, and *a b c* the half-revolution of the crank-pin simultaneously described. Let the path of the crank-pin be divided into equal parts at the points 1, 2, 3, 4, and draw verticals from the points of division to the line *a c*; then, as the angular speed of the crank is uniform, and the divisions of the circular path *a b c* are equal, the line *a c* will be divided by the perpendiculars already drawn into segments representing spaces described by the piston in equal times, and therefore also the varying average velocity of the piston in the same spaces. Whence it is obvious that the speed of the piston, during one stroke, begins and ends at nothing at the extreme or dead points, *a, c*; that it accelerates towards *b*, the position at half-stroke, when it reaches a maximum, and that beyond this point it is retarded till it gains the end of its stroke. The two halves of the stroke are described in equal times, and in these halves the variation of the velocity of the piston are exact counterparts.

When the connecting-rod is in this discussion supposed to be indefinitely long, it is so supposed for the occasion, as an equivalent for the supposition that the piston keeps pace exactly with the movement of the crank-pin in the direction of the centre line of the engine, between one end of the stroke and the other.

The obliquity of the connecting-rod destroys the symmetry above observed. In a stroke of the piston there are three cardinal points—the commencement, the middle, and the termination of the stroke. According to the preceding diagram, these three points are arrived at by the piston simultaneously with the horizontal and vertical positions of the crank. But the angularity of the connecting-rod at half-stroke of the piston virtually shortens its length, and the crank-pin is by as much short of its midway position. As the crank-pin is presumed to move with a uniform angular velocity, it follows that the piston describes the two halves of its stroke with different average volocities, and in unequal times. In an engine, for example, with a stroke of 24 inches, having the crank 1 foot, and the connecting-rod 5 feet, long, or five times the length of the crank, it is found from the annexed diagram of the relative

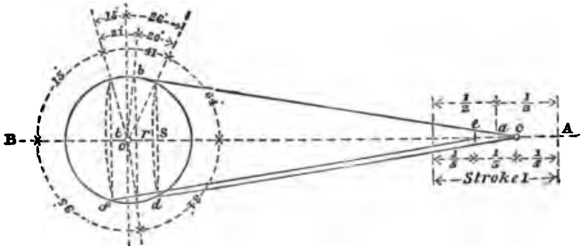


Fig. 109.

positions of the piston and the crank that, at half-stroke of the piston, the connecting-rod *a b* falls short of the vertical centre line of the crank by the amount *o r*. Dividing the stroke of the piston into three equal parts, the connecting-rod being in the relative positions *c d*, *e f*, the distances of the points *d*, *f*, from the centre line are *o s*, *o t*, respectively about 3 inches and 5 inches. The corresponding angular positions of the crank are, for the half-stroke of the piston, 6° with the vertical; and for the one-thirds of the stroke respectively 14° and 24½°. The sum of 14° and 24½°, or 38½°, is the angular motion of the crank during the middle third of the stroke, and the complements of those, 76° and 65°, are the angular motions for the extreme thirds. The average speeds of the piston, therefore, in describing the successive thirds of its stroke in the direction *a c*, are inversely as 76, 38½, 65½, or directly as 1, 2, 1·16, nearly; and the two halves of the whole stroke are described with average speeds inversely as 96° to 84, or directly as 7 to 8. The shorter the connecting-rod, the greater is the irregularity so introduced into the motion of the piston. The general effect, therefore, of the connecting-rod on the motion of the piston is, that the piston arrives sooner at the positions which it would occupy if the connecting-rod were "indefinitely" long at all points throughout the front stroke, which is described towards the crank; and that throughout the back stroke the piston is in the same degree behind the positions which it would occupy for all positions of the crank if the connecting-rod were indefinitely long.

Motion and Action of the Slide-valve in relation to the Motion of the Piston.

As the path of the crank-pin is represented by a circle, and the stroke of the piston by a straight line equal to the diameter of that circle, so also the path of the eccentric is represented by a circle, and the travel of the slide-valve by a straight line equal to the diameter of the eccentric circle; assuming, for the sake of illustration, that the valve is actuated in direct connection with the eccentric. If, then, two circles be described on a common centre *c*, Fig. 110, for the crank path and the eccentric path respectively, their diameters A B, *a b*, are the stroke of the piston and the travel of the valve. When the piston is at one end of the stroke, at A′, the valve is opening the port at *a*′, and is just as much in advance of its middle position over the ports as is needed to draw the lap clear off the edge of the port at *a*′, in addition to the lead or opening of the port at the beginning of the stroke. The position of the eccentric, then (represented by its own revolving centre), must be at the point *a*′, which is in advance of its position at half-throw, in the line D E, by as much as the lap plus the lead. As the axle revolves, the valve is further opened by the retiring eccentric till it falls into the line A B, when the crank is getting on to half-throw. When the crank has attained to half-throw, in the position *c* D, the eccentric is on its way returning, and the motion of the valve is reversed on the way to close the port. The port is actually closed some time before the valve and the eccentric return to their midway position—the former over the ports, and the latter in the line *c* E—in virtue of the lap on the valve. Further, when the valve and the eccentric do arrive at their middle positions, half-

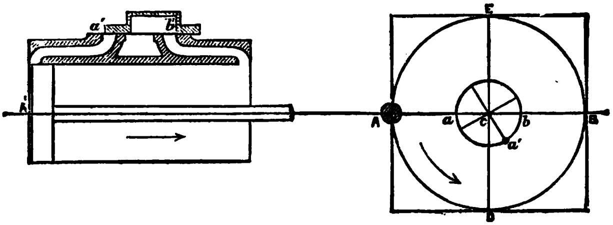


Fig. 110.

travel and half-throw, the edge of the cavity of the valve coincides with the inner edge of the steam port, and the opening of the port to the exhaust passage, through the medium of the cavity, is forthwith established by the progressive motion of the valve. All that has just been described of the operation of the eccentric on the valve is effected before the crank completes a half-revolution—that is, before the crank-pin arrives at the point B, and, consequently, completes its stroke. The valve, indeed, makes another change before this: it opens the other port at *b′* for the other end of the cylinder, the lap having been completely withdrawn, and an additional movement for the lead effected just as the stroke is completed.

The successive positions occupied by the valve during a revolution of the crank may be graphically represented as in Fig. 111, where A B and *a b*, being the circles of the crank and the eccentric respectively, are divided into any equal number of parts, of which the points A, *a′*, are respectively the positions of the crank and the eccentric at the beginning of the stroke; the other points B, *b′*, D, *d′*, E, *e′*, show the simultaneous positions of the crank and eccentric at intervals

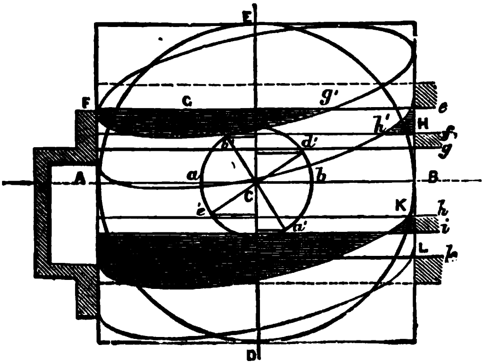


Fig. 111.

of one-fourth of a revolution. Draw the lines *e*, *f*, *g*, *h*, *i*, *k*, parallel to the centre line A B, spaced apart at intervals equal to the exhaust and steam ports, and the intervening bridges; *e f* and *i k* being the steam-ports, and *g h* the exhaust port. Place the valve on the perpendicular at A, in the right position with respect to the parallels *e*, *f*, *k*, for the commencement of the stroke, showing the requisite lead at F, and set off its position on the face of the diagram according with the position of the crank. The elliptic lines, traced so as to connect these positions, represent the linear motion of the valve relative to the ports and to the crank, and with the aid of a little shading they clearly show the successive periods and changes of the distribution, subject of course to correction for the angularity of the connecting-rod. The shaded space, G, shows the period of admission, terminating at *g′*; and the shaded space, H, the period of exhaustion, commencing at *h′*. The shaded space, I, shows the exhaustion for the alternate end of the cylinder, K the compression, and L the short period of pre-admission of steam for the following stroke.

On the same system, diagrams of motion may be constructed for any proportions or other species of valve, whether double or superposed valves, conical valves moved by cams, or with conditions otherwise varied. The link-motion, as a variable-expansion gear, operates by varying the travel of the valve, the extra expansion, and diminished period of admission, being affected by the shortening of the travel; the result being precisely the same as if an eccentric of correspondingly smaller throw were substituted for an eccentric of greater throw.

CHAPTER XVIII.

STEAM-INDICATOR.

The steam-indicator is an instrument for measuring and registering the pressure of the steam working in the interior of a steam-cylinder; and it contains two motions for these purposes respectively. For the purpose of measuring the pressure, a small piston is movable in a small cylinder, one end of which is in direct communication with one end of the interior of the steam-cylinder, the other end of the small cylinder of the instrument being open to the atmosphere. The piston of the instrument is attached by the medium of its spindle to a helical spring which surrounds the spindle, the other end of the spring being fixed to the cylinder; and when exposed to the pressure of the steam in the steam-cylinder, the piston of the instrument rises in proportion to the pressure, or, on the contrary, it falls below the level of atmospheric pressure in proportion to the degree of vacuum.

For the purpose of registering the pressure measured in the way just described, a small sheet of paper is lapped and clamped round a brass cylinder which turns on a fixed pivot, parallel to the spindle of the piston. It is pulled round in one direction by a cord connected with the crosshead of the steam-cylinder, through a lever for reducing the length of traverse of the steam-piston to a length suitable for a reciprocation of the paper-cylinder. For the return stroke, the cylinder is pulled back the reverse way, by a flat spring coiled within it; and thus a reciprocating circular movement of the paper-cylinder is effected, by which the surface of the paper is impressed with a reciprocating movement similar, in miniature, to that of the steam-piston. To register the pressure on the paper, a pencil attached to the spindle of the helical spring is turned upon the surface of the paper, and marks all the variations of pressure that take place in the steam-cylinder, on one face of the piston, throughout the course of a double stroke. In McNaught's indicator, the piston is fully $\frac{3}{8}$ inch in diameter, having an area of $\frac{1}{8}$ square inch; the tension of the helical spring, for high pressures, increases at the rate of 40 lbs. per square inch to the inch of rise; for low pressure, and the measurement of vacuum, the tension is at the rate of 20 lbs. per square inch pressure per inch of rise or fall.

Richard's indicator was designed to obviate the objection to most other indicators when applied to engines moving at high speeds, namely, the excessive weight of the reciprocating parts, which, by their momentum, disturb the action of the pencil, and to a certain extent vitiate the diagram. McNaught's indicator is to some extent open to this objection; but, whilst it is to be desired that an indicator should describe precisely the degree of pressure as well as the variations of pressure in the cylinder, it must be added that the figures described by McNaught's indicator are susceptible of being reduced to the normal form, the disturbance being eliminated from them. In Richard's indicator, the weight of the moving parts is reduced as much as possible; a short spring is used, and the range is multiplied by a lever, which is formed with another lever into a parallel motion, to carry the pencil in a straight line. The pencil is, in fact, a pointed brass wire, which marks on prepared metallic paper, and is lighter, stronger, and more durable than black-lead pencils. A common pin with a blunt point makes a good line.

CHAPTER XIX.

GENERAL ACCOUNT OF THE ACTION OF STEAM IN THE CYLINDER AS REPRESENTED BY THE INDICATOR-DIAGRAM.

THE action of steam is developed in its most simple form in the non-condensing engine, in which the question of the vacuum has no part; and the editor will, therefore, proceed with a summary of his experimental investigations of the behaviour and condition of steam in non-condensing engines chiefly of the locomotive class, first published by him, in 1851, in "Railway Machinery," and subsequently in the article "Steam-Engine" in the eighth edition of the "Encyclopædia Britannica." Since the first publication of these investigations, comprising an experimental demonstration, by the author, of the great loss by condensation of steam in the cylinder when attempted to be worked expansively,—then demonstrated, he believes, for the first time,—the subject has been frequently revived. The editor's conclusions have been variously confirmed, and the necessity for the steam-jacket, or equivalent means of maintaining, or contributing to maintain, the expanding steam at a suitable temperature is now generally acknowledged.

In illustration of the function and utility of the indicator, by means of which most of the editor's observations were conducted, examples of indicator-diagrams, obtained by him from one of the cylinders of a locomotive, are illustrated in Fig. 112.

The base line A B is the line of atmospheric pressure, and represents the stroke of the piston; and the rectangular space above it may be supposed to be the interior of the cylinder. The heavily lined figure is a diagram of the indicated action of the steam, when the piston moved in the cylinder at an average slow speed of 40 feet per minute, and shows by its angularity how the steam is controlled by the valve, and the precise points of the stroke at which the changes of the distribution take place. The piston is represented as having started from the right-hand end of the cylinder, under a uniform pressure of 61 lbs. steam above the atmosphere, traced from the upper right-hand corner, till it reaches the point of suppression. The admission being terminated, the period of expansion is commenced; the pressure declines as the piston advances before the expanding steam, and continues to do so till the piston reaches the point of release. At this point, the piston enters on its third and last stage of progress, toward the end of the steam-stroke; the steam, primarily admitted at 61 lbs. above the atmosphere, and attenuated to 23 lbs. pressure previously to being released, quickly discharges itself into the atmosphere,

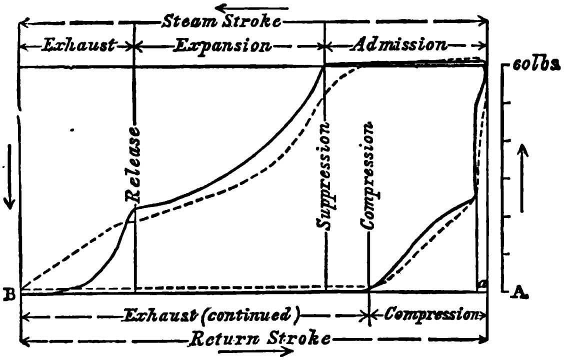


Fig. 112.

in virtue of its remaining elasticity, and is entirely evacuated before the end of the stroke, as indicated by the quick and total decline of the steam-line during the period of exhaust towards the point B. The evacuation is, however, only relative, not absolute, as steam of atmospheric pressure remains in the cylinder, though not obviously sensible in the indicator-diagram; during the return-stroke, therefore, the valve ought to maintain the exhausted end of the cylinder continuously open, to allow the steam of one atmosphere of pressure to escape before the returning piston. The benefit of this provision is proved by the diagram, in which it appears that during the continuation of the exhaust the steam of latent pressure remains at the zero-point of the scale; at the instant of closing or compression, however, when there is no longer an exit for the latent steam before the piston, the diagram-line slopes upwards towards the right-hand side, and the steam is compressed against the end of the cylinder. While the volume of the compressed steam is being thus forcibly reduced, the density is increased; the pressure is raised, until the accumulation of back pressure so induced is merged in the superior pressure of the steam admitted by anticipation, during the small remainder of the return-stroke marked *a*, for the business of the next steam-stroke.

The behaviour of the steam in the cylinder may thus, with the aid of the indicator-diagram, the different sections of which are distinctly marked, be clearly traced through the cycle of changes. The period of admission, in the example just described, is, it appears, about one-third of the whole stroke; that of expansion is something more, and a simple inspection of the diagram shows that, in this instance, one-half of the work of the steam is performed by simple expansion while shut up in the cylinder. Even the period of exhaust supplies its quota of effect, inasmuch as the evacuation is a work of time, and the extra positive pressure so yielded is represented by the small triangular space between the point of release and the end of the stroke at B. The force developed by compression is properly designated resistance, as it is opposed to the motion of the piston, and must be classed with the slight opposition also made by the entering steam during its pre-admission at *a* for the steam-stroke.

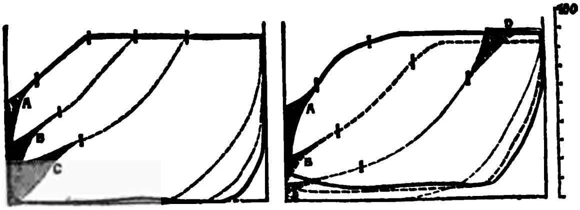
But the important inquiry remains, How is the behaviour of the steam affected by the speed of the piston? If the piston move slowly, there is plenty of time for the steam to go through its mechanical duties. While the steam is admitted, it follows up the piston at full pressure; while the exhaust is open, it thoroughly evacuates itself. But, at higher speeds, the time for each evolution is proportionally shortened; and it remains to be considered in what way this acceleration of work is discharged. The dotted-line diagram (Fig. 112) illustrates the behaviour of the steam in the same cylinder, under the altered circumstance of a higher speed of piston, averaging 310 feet per minute, other circumstances being the same. The steam enters at an initial pressure of 62 lbs. per square inch, but suffers a slight reduction of pressure as the piston recedes before it—a circumstance which may at once be attributed to the accelerating speed of the piston in the cylinder specifically due to the nature of the crank-motion, and the consequently greater difficulty of following it. The reduction, however, is not considerable, and it is only when the piston nears the point of suppression, and the port is nearly closed by the valve, that the pressure rapidly falls in the diagram towards the suppression-line. This is a case of simple wire-drawing, as the opening of the port, previously wide enough to admit all the steam that could find its way into the cylinder against the frictional resistance and bends of the passage, is now reduced to a minimum width consistent with this condition, and a further contraction and final closing necessarily occasion an accelerated fall of the pressure. The pressure at the instant of suppression, or cut-off, under these circumstances, is 54 lbs. above the atmosphere. The curve descends during the period of expansion, and cuts the line of release at a pressure of 19 lbs., and on reaching the end of the stroke it attains a minimum of 2 lbs. of pressure per square inch. The curve of expansion, it appears, runs into those of the admission and the exhaust, without any of the abruptness which distinguishes the slow diagram; the fact being that expansion, technically so called, had begun before the steam was nominally cut off—a result implied in wire-drawing; and there was, therefore, not the same liability to sudden change of pressure on entering the period devoted to expansion. At the termination of the period of expansion, the curve crosses the exhaust line nearly at right angles, and barely reaches the minimum pressure when it arrives at the termination of the stroke.

The comparative delay so evinced in the accomplishment of the exhaust is plainly a consequence of the shorter time allowed for this purpose in consequence of the greater speed of the piston; and, accordingly, one perceives a material accession to the area of the diagram, or the useful effect of the steam, in the very circumstance that it exhausts less freely. On the other hand, a drawback on this additional effect exists in the sustained back pressure of 2 lbs. per square inch, as indicated during the return-stroke, referable to the same cause—imperfect exhaustion. The exhaust-line runs into the compression-line with a slight bend; and it is observable that, before the pre-admission of steam for the next stroke takes place, the compressed steam attains to a higher pressure than that found by the slow diagram—a circumstance to be explained by the greater delay in the rise of pressure at the lower speed, caused by greater condensation of steam in the cylinder. But, though the curve of high speed is in advance of that of the low speed at the instant of admission of fresh steam, it falls behind at the commencement of the stroke. At this point the pressure does not get beyond 51 lbs. above the atmosphere, and only attains the maximum, 62 lbs., when the piston has described two and a half per cent. of the steam-stroke. This deficiency is attributable chiefly to the shortness of time allowed for the re-establishment of the working pressure, and indicates, in this instance, the need for more lead of the valve.

The Action of Steam in the Cylinder during Admission.

In the flow of steam from the boiler to the cylinder, it meets with hindrances to its passage which usually operate to cause a considerable reduction of pressure when it reaches the cylinder, even if all the passages be thrown wide open. The actual charge of steam transmitted through an irregular passage of considerable length, and of a given sectional area, is, in all cases, less than what can be passed through an aperture of a very short length, as, for example, an aperture in a thin plate of the same sectional area, owing to the bends and lateral friction of the long passage. It therefore frequently happens that the opening of the port allowed by the valve, though it may be much less than the total area of the port, is sufficiently large to pass all the steam that can force its way along the passage. This fact is constantly exemplified in practice: it is known that the opening of the port beyond a certain amount, which is in all cases less than the area of the port itself, ceases to be advantageous in facilitating the passage of the steam into the cylinder. Similarly, the opening of the regulator, or "throttle-valve," beyond a small fraction of the sectional area of the steam-pipe, does not add to the available pressure at the valve-chest. When the steam is not dry, containing water in suspension, the labour of moving in passages is greatly increased, owing to the quantity of dead, inelastic weight to be dragged along; and the reduction of pressure is consequently much more than with dry steam.

Directing attention, for the present, to the behaviour of steam within the cylinder, it is to be premised that, notwithstanding the objection that has been urged against the ordinary slide-valve, worked by an eccentric motion—the want of sufficient celerity of action—there is no material wire-drawing of the steam by the closing valve when the period of admission exceeds two-thirds of the stroke, unless at very high speeds of piston, exceeding from 500 to 600 feet per minute. When the steam is cut off at shorter periods, however, the travel of the valve being less, and therefore, also, its velocity of motion, the wire-drawing increases at high speeds, though at low speeds it does not. For example, the indicator-diagrams (Figs. 113, 114) were taken from a locomotive cylinder 18 inches diameter, 24 inches stroke; steam-ports 13 by 2 inches; exhaust port 13 by $3\frac{1}{2}$ inches; lap of valve outside $1\frac{1}{4}$ inch; inside $\frac{1}{16}$ inch. Each figure shows three diagrams for periods of admission, respectively 16, $11\frac{3}{4}$, and 7 inches of the stroke, the terminations of which, and of the expansions, are pointed off on the figures. For the first figure, the speed of piston was 240 feet per minute; for the second, 770 feet per minute. The wire-drawing at the lower speed was obviously nothing; at the higher speed, the pressure fell 3 lbs., 12 lbs., and 25 lbs. below the initial pressure, before the steam was cut off, doubtless explained by the fact that, in the three cases, the travel of the valves was respectively $4\frac{3}{4}$, $3\frac{15}{16}$, $3\frac{7}{16}$ inches; and the maximum open-



Figs. 113, 114.

ing of the port was 1$\frac{1}{32}$, $\frac{11}{16}$ nearly, and $\frac{1}{2}$ inch. It was found, however, that, in the third case, with the shortest admission, the steam-line was practically straight and parallel to the atmospheric line, at speeds of piston up to 450 feet per minute. In inferiorly arranged engines, with short lap and short travel of valve, wire-drawing is considerably greater than in the example just illustrated. With the same sizes of cylinders, a $\frac{5}{8}$ inch lap wire-draws considerably more than 1 inch lap of valve.

Long lap, in conjunction with wide ports, reduces the wire-drawing to a minimum. The more dry the steam is, the more susceptible it is of apparent wire-drawing as indicated in the cylinder, because dry steam enters the cylinder more freely than wet steam, and attains a higher initial pressure.

As to the quantity of lead of the valve needful to ensure ample and timely admission of steam into the cylinder at the commencement of the stroke, one-fifth of the length of the steam port is sufficient. When the lead is excessive, the steam is admitted so readily as to be momentarily compressed, and to cause, in some cases, an unfavourable pulsatory action of the steam. The total absence of lead likewise occasions an unsteady pulsatory action in the cylinder. If lead is deficient or wanting, the maximum pressure of steam in the cylinder is not attained until after a portion of the stroke is traversed by the piston.

The Action of Steam in the Cylinder during Expansion.

When steam is admitted into the cylinder while the latter is comparatively cold, or colder than the steam, a very sensible condensation of the steam takes place during admission, in the process of heating the cylinder to the temperature of the steam, which continues to a certain extent during the period of expansion. A portion of this heat, though but a small part, passes off and is lost; the remainder is retained by the cylinder until it is re-absorbed by the precipitated steam, during the expansion of the remaining steam, if it be long enough continued; that is, until the temperature of the latter falls below that of the cylinder. This is a destructive process, occasioning an absolute loss of steam; and the amount of steam thus injuriously precipitated, and but partially revived, increases rapidly in proportion as the steam is earlier cut off, and expansion is extended. In the cylinders of ordinary steam-engines the extra consumption and waste of steam devoted to the heating of the cylinder in the first part of the stroke is above 12 per cent. of the whole steam consumed for a period of admission of one-third of the stroke. In exposed locomotive-cylinders, the loss is proved to amount to nearly 40 per cent. of the whole steam consumed, when cut off at one-eighth of the stroke.

This important species of loss is inseparable from the attempt to work steam expansively where there is no provision for the heating of the cylinder, and maintaining it at a suitably high temperature—equal at least to the initial temperature of the steam. The magnitude of the loss is so great as to defeat all such attempts at economy of fuel and steam by expansive working, and it affords a sufficient explanation of the fact, in engineering practice, that expansive working has been found to be expensive working, and that, in many cases, an absolutely greater quantity of fuel has been consumed in extended expansive working while less power has been actually developed.

With respect to the ratio of pressure to expansion of steam in cylinders, observed in ordinary practice, it may be sufficient to remark in this place that the quantity or weight of steam in the cylinder is the same throughout the process of expansion, estimated in terms of the pressure and the volume of steam, as saturated at different points of the stroke, when the steam is dry and the temperature of the cylinder is properly maintained; and that, consequently, the pressure of expanding steam in a cylinder, under such circumstances, may be determined with sufficient accuracy for any degree of expansion, in terms of the ascertained density of saturated steam. On the contrary, in cylinders imperfectly heated, where the steam is partially precipitated during admission, and during the first part of the expansion, the expanding pressure at first declines more rapidly than would be due to the maintenance of a constant quantity of steam, and afterwards less rapidly, rising above the expanding line of pressure proper for a constant weight of steam—equal to that contained in the cylinder at the commencement of expansion. This want of conformity is exemplified in a diagram taken from an outside-cylinder locomotive, with a stroke of 24 inches, at a low speed, in which the dotted lines show the expansion-curve which would have been described with a constant weight of steam. This process of successive condensation and re-evaporation is distinctly indicated, for no sooner is the steam cut off at A than condensation is made visible by the vertical sinking of the expansion-curve below the standard or normal curve, until the temperatures of the steam and the material of the cylinder become equal, when, as the pressure continues to fall, and the temperature of the steam with it, the curve rises and crosses the normal curve at C in virtue of a partial re-evaporation of the steam previously precipitated, caused by the cylinder itself, which, at first colder than the steam, and heated by it in the first stage of the expansion, becomes then relatively hotter, and partially restores the heat of which it had previously robbed the steam. The process of restoration of heat goes on to the end of the expansion, as further proved by the increasing excess of the indicated above the normal pressure at the point D, amounting to above 10 lbs. per square inch at the point of exhaustion.

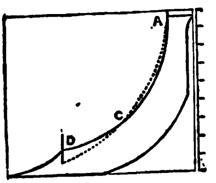


Fig. 115.

That the condensing power of an unprotected cylinder is something very considerable, is rendered very obvious by an indicator-diagram, Fig. 116, taken from the same cylinder, in full gear, at a low speed, shortly after starting with a train. It shows that the pressure could not be maintained in the cylinder, as condensation in heating the cylinder proceeded faster than steam could be supplied through the opening of the port. Had the cylinder been hot, the pressure would have been fully maintained, according to the dotted line.

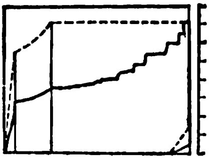


Fig. 116.

The Action of Steam in the Cylinder during Exhaustion.

In no part of the distribution is the advantage of time more apparent than during the period of exhaust. It is plain, by reference to Figs. 113, 114, that the steam does not discharge itself instantaneously from the cylinder at the point of release, as the piston, in all diagrams, has visibly to go some distance before the pressure falls to a minimum. In the left-hand figure, at the lower speed, the piston moves 3½ inches from the point at which the steam is released, to the point at which the pressure falls to the atmospheric line. At the higher speed the steam only reaches the minimum pressure of 2 lbs. when the piston has attained to the end of the stroke, through 5 inches of the cylinder. These are elementary proofs of the benefit of time for ensuring a good exhaust.

As the velocity of steam escaping uninterruptedly would practically suffice to evacuate the cylinder in good time, to prevent the evil of back pressure, there is no doubt that the back pressure which does actually arise is owing to the circumstantial hindrance of mixed water, strictures, bends, and friction. The retarded motion of the piston towards the end of the stroke, in virtue of the action of the crank, is peculiarly favourable for the exhaustion of the steam, as it allows time for its escape before the piston returns upon it. At the higher speeds, however, the escaping steam may be overtaken and driven before the piston into the atmosphere, should its remaining elasticity prove insufficient, and then an opposing back pressure is established. The wider the lead for the exhaust the less is the back-pressure, on account of the increased facility for escape. For the usual speeds of pistons of stationary engines—from 220 to 300 feet per minute—the back pressure is inconsiderable, if the cylinder be properly heated and the steam be dry. On the contrary, the back pressure is very great when the steam is condensed within the cylinder, or if it be loaded with water by priming.

The evil of condensation in a cylinder, in causing back pressure, was clearly proved in the case of a locomotive, into the cylinder of which steam was admitted at 80 lbs. pressure above the atmosphere, cut off at one-sixth of the stroke and exhausted at half-stroke. It was so loaded with water when discharged that it incurred a back pressure of 12 lbs. per square inch in being expelled by the piston, which was moving at an average speed of 430 feet per minute. Shortly after, when the steam was admitted in a much greater volume, through half the stroke, at a speed of piston of 580 feet per minute, the exhaust pressure only amounted to about 2½ lbs. per square inch. The cylinder had been previously heated by hard work; the steam was comparatively dry; and the opposing pressure was, consequently, almost entirely removed.

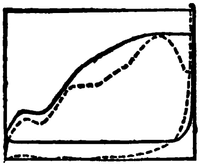


Fig. 117.

The ordinary effect of the priming of muddy water from a locomotive boiler is illustrated by Fig. 117, in which are shown indicator-diagrams taken from the cylinder immediately previous and subsequent to blowing-off the boiler, when the water had been unusually impure, at the same speed of piston, about 600 feet per minute. The full line was described before, and the dot-line after, the boiler was supplied with clean water; and, other circumstances being the same, the back pressure fell from 9 lbs. to about 1¼ lb. per square inch above the atmosphere. In some cases the priming of water into the cylinder has been found to reduce the effective pressure more than a half.

Summary of Data as to Back-pressure.—If the steam working in steam-engines could escape freely without resistance, the back pressure would be simply the pressure of the atmosphere in non-condensing engines; and in condensing engines it would be the pressure corresponding to the temperature in the condenser—what Professor Rankine calls the "pressure of condensation." The mean back pressure, however, always—sometimes considerably—exceeds the pressure of condensation. One cause of this, in condensing engines, is the presence of air mixed with the steam, which causes the pressure in the condenser, and also the back pressure, to be greater than the pressure of condensation of the steam. The ordinary temperature in the condenser, in proper working order, is about 104° Fahr., for which the pressure is 1·06 lb. per square inch, whilst the actual pressure in the best condensers of ordinary engines may be scarcely ever less than 2 lbs. on the square inch. The principal cause, however, of increased back pressure is resistance to the escape of the steam from the cylinder, amounting to from 1 lb. to 3 lbs. per inch greater than the pressure in the condenser. There is no doubt that, practically, in condensing engines, the back pressure increases with the speed of the engine, and also with the density of the exhausted steam, and with a reduced size of the exhaust ports. In locomotive engines, which are non-condensing, the Editor has found that the excess of back pressure above the atmospheric pressure varies nearly as the square of the speed, as the pressure of the exhaust steam at the commencement of the exhaust, and inversely as the square of the area of the orifice of the blast-pipe; that it is less the greater the ratio of expansion; that it is less the longer the time during which the exhaustion of the steam lasts; and that it is increased by the presence of liquid water amongst the steam.

CHAPTER XX.

THE WORK OF STEAM BY DIRECT PRESSURE WITHOUT EXPANSION.

The functions of the cylinder and piston of a steam-engine may, sinking details, be illustrated by means of a tall cylinder open at the upper end, into which a piston is inserted, with a quantity of water in it at the bottom, and a fire applied below to convert the water into steam.

Let A, Fig. 118, be an upright cylinder open at the top, and about 13½ inches in diameter inside, having a sectional area of one square foot. Let P be a piston or disc, exactly fitting the cylinder, so as to slide up and down in it without friction, and at the same time to prevent the passage of steam or air from one side to the other. Suppose that there is one pound of water at the bottom of the vessel, and that the piston rests upon it. If a fire be lighted beneath the vessel, so that heat is communicated to the water, the temperature of the water will be raised to 212° Fah. before any steam is generated from it, inasmuch as the water is subject to the pressure of the atmosphere, transmitted to it

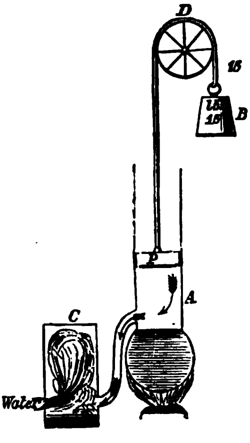


Fig. 118.

through the piston. When the temperature reaches 212°, the heat of the fire being continued, steam will be formed and disengaged under the piston, and, from the commencement of the formation of steam, the piston will be raised by the steam, with its atmospheric load of 14·7 lbs. per square inch, amounting to 2,116·8 lbs. on the square foot area of the piston. The piston will continue to be raised as water continues to be evaporated and steam formed. When the whole of the water is evaporated, the piston will be raised to a height of 26·36 feet above the bottom of the cylinder. That is, the pound of water is evaporated into saturated steam of atmospheric pressure, and occupies a volume equal to 26·36 cubic feet; for, the sectional area of the piston being equal to one square foot, and the height to which it is raised being 26·36 feet, the capacity or volume of the steam is

$$1 \times 26{\cdot}36 = 26{\cdot}36 \text{ cubic feet.}$$

This is the space described by the piston; and the work done by the steam on the piston—the initial work—consists in having lifted a weight of 2,116·8 lbs. through a height of 26·36 feet. This performance is expressed in foot-pounds by the product of the weight into the height through which it is lifted, namely,

$$2116{\cdot}8 \text{ lbs.} \times 26{\cdot}36 \text{ feet} = 55{,}799 \text{ foot-pounds.}$$

The initial work done by 1 lb. of atmospheric steam in this example, namely, 55,799 foot-pounds, is equivalent to raising a weight of 55,799 lbs. through a height of 1 foot; and, as a unit of heat is equivalent to the raising of 772 lbs. 1 foot high, the above performance may be expressed in units of heat converted into work by dividing 55,799 by 772, thus—

$$\frac{55{,}799}{772} = 72{\cdot}3 \text{ units.}$$

But the experiment may be varied, by doubling artificially the quantity of the pressure on the piston exerted by the atmosphere; or by doubling the resistance to the ascent of the piston, by placing an additional load on the piston as it rests on the surface of the water in the upright cylinder, equal to the pressure of the atmosphere. The load will in this way be increased to a pressure, in round numbers, of 30 lbs. per square inch, of which 14·7 lbs. is atmosphere-pressure and 15·3 lbs. is the added pressure; and the total load will be equal to 4,320 lbs. on the square foot area of the piston. Heat being again applied, the temperature of the water will be raised to 250·4° Fah., and at this point it will become stationary; evaporation will commence, and will proceed with the continued application of heat, until, as before, the whole of the water is evaporated. At this stage, the piston, with its load, has been raised to a height of 13·46 feet.

Here it appears that a load slightly more than double the atmospheric resistance is raised through a height slightly more than half that through which the simple atmospheric load was raised; and the initial work done by 1 lb. of water evaporated into saturated steam of a pressure of 30 lbs. per square inch is found, as before, by multiplying the total load by the height through which it was raised, thus—

$$43{\cdot}20 \times 13{\cdot}46 = 58{\cdot}147 \text{ foot-pounds,}$$

and the equivalent in units of heat is

$$\frac{58{,}147}{772} = 75{\cdot}3 \text{ units.}$$

Suppose, again, that a double additional load be laid upon the piston of the upright cylinder, Fig. 118, making a total resistance, including that of the atmosphere, of 45 lbs. per square inch, or 6,480 lbs. on the square foot area of the piston. If 1 lb. of water be generated into saturated steam under this pressure, the piston will be raised to a height of 9·18 feet.

In this case a load slightly more than three times the atmospheric resistance is raised through a height which is a little more than a third of the height through which the atmospheric resistance alone was lifted; and the total work done is equal to

$$6480 \text{ lbs.} \times 9{\cdot}18 \text{ feet} = 59{,}486 \text{ foot-pounds};$$

and the equivalent, in units of heat, is

$$\frac{59{,}486}{772} = 77{\cdot}1 \text{ units.}$$

Dealing now with a load on the piston double the last, or approximately six atmospheres, equal to, say, 90 lbs. pressure per square inch, or 12,960 lbs. per square foot, the steam formed by the evaporation of 1 lb. of water will raise the piston to a height of 4·79 feet, which is between a fifth and a sixth, or 2-11ths, of the height to which the atmospheric resistance alone was removed. But, the work done is

$$12{,}960 \text{ lbs.} \times 4{\cdot}79 = 62{,}074 \text{ foot-pounds,}$$

to which the equivalent, in units of heat, is

$$\frac{62{,}074}{772} = 80{\cdot}4 \text{ units.}$$

To compare the gross performances of the saturated steams generated from 1 lb. of water, in these examples, they stand as follows:—

Resistance. Atmos.	Pressure of Steam. lbs. per sq. in.	Volume of Steam. Cubic feet.	Gross work done. Foot-pounds.	Equivalent Heat converted into Work done. Units.
1	14·7	26·36	55,799	72·3
2	30	13·46	58,147	75·3
3	45	9·18	59,486	77·1
6	90	4·79	62,079	80·4

From this statement, it appears that the volumes occupied by the steam generated under increasing pressures are reduced nearly in the inverse ratio of the pressures, but not quite so fast; so that, as a result, the products of the pressures by the volume or the gross work done by the steam, is nearly the same for the different pressures, though it is slightly increased with the increase of pressure, and, of course, also the number of units of heat converted into work done. In fact, the gross work done against two atmospheres is 4 per cent. more than against one; and against six atmospheres it is 11 per cent. more.

But the total heat expended in generating 1 lb. of steam also rises with the pressure, and the proportion of such total heat converted into work in the respective cases above detailed, are as follows, it being assumed that the water is supplied to the boiler at 212° Fah.:—

Pressure of Steam. lbs. per sq. in.	Total Heat of One Pound of Steam, Units.	Proportion of Total Heat converted into Work (as above). Units.
14·7	965·2	72·3 or 7·5 per cent.
30	976·9	75·3 ,, 7·7 ,,
45	984·2	77·1 ,, 7·8 ,,
90	998·2	80·4 ,, 8·0 ,,

showing that the proportion of the total heat converted into work rises sensibly, though slightly, with the pressure under which the steam is generated. In the above examples, the efficiency rises from 7·5 to 8 per cent., and it indicates that steam of higher pressure does slightly more work than steam of lower pressure, and that about 1-13th of the total heat consumed is converted into work.

Useful Work done by the Steam in the foregoing Examples.

Though the gross or absolute performance of the steam at the different pressures does not greatly vary, yet the useful work done, reckoned as over and above that which is consumed in opposing the atmospheric resistance, increases in marked proportions as the pressure is increased.

The work done by steam generated at atmospheric pressure was entirely absorbed in opposing the resistance of the atmosphere, and no useful work was done.

In the second instance, the steam raised a load in addition to the atmospheric pressure, though it was raised to only half the height to which the piston ascended in the first instance. Still it was useful work; that is to say, it was work which was serviceable—mechanically raising a load. In general terms, half the whole work done by the steam was utilised. But it will be well to examine more precisely into the disposal of this work. The atmospheric resistance, 2,116·8 lbs., was opposed through a height of 13·46 feet, and the work so expended was

2116·8 lbs. × 13·46 = 28,492 foot-pounds,

whilst the work expended in raising the additional load of 15·3 lbs. per square inch, or 2,203·2 lbs. on the square foot of the piston, was

2203·2 lbs. × 13·46 = 29,655 foot-pounds.

Adding the two portions of work together,

Useless work opposing the atmosphere	28,492, or	49 per cent.
Useful work, raising a weight . . .	29,655, or	51 „
Total work done . . .	58,147	100

It is shown, as was before determined, that the whole of the work amounted to 58,147 lbs.; of this a little more than a half was useful work.

With respect to the third example, a double load was raised, in addition to the resistance of the atmosphere, through a height of about a third of the height in the first instance; and the work was distributed as follows:—

	Foot-pounds.	
Useless work against the atmosphere, 2116·8 × 9·18 . . . . =	19,432, or	33 per cent.
Useful work, raising a weight, 4363·2 × 9·18 . . . . =	40,054, or	67 „
Total work done . . .	59,486	100

Here it appears that the total work done is slightly greater than in the previous instance, whilst two-thirds of it is usefully applied, and only a third was expended against the atmospheric resistance.

In the fourth example, a total load of six atmospheres was raised through a height of more than one-sixth of the height in the first instance, but five-sixths of the work was useful, as follows:—

	Foot-pounds.	
Useless work against the atmosphere, 2116·8 lbs. × 4·79 . . . . . =	10,141, or	16·3 per cent.
Useful work, raising a weight, 10,843·2 lbs. × 4·79 . . . . . =	51,938, or	83·7 „
Total work done . . .	62,079	100

Generally, whatever be the load imposed on the piston, a deduction must be made from the total duty, of a quantity which is necessary for repelling the atmosphere, in order to ascertain the available duty.

Such are precisely the conditions of a non-condensing steam-engine worked without expansion, the steam being admitted behind the piston throughout the whole of the stroke, and then discharged into the atmosphere. The evidence above adduced goes to prove that, other circumstances being the same, the higher the pressure of steam in the non-condensing cylinder, the more efficiently is the steam worked.

Efficiency of the Heat applied.

It was shown (page 278) that from 7½ to 8 per cent., or about one-thirteenth of the total heat consumed, is converted into work. Of this work, again, the proportions utilised were found to be as follows:—

Press. of Steam. lbs. per sq. in.	Work Utilised. foot-pounds, or units of heat.		
14·7	nil.	nil.	
30	29,655, or 38·4 per cent.	= 3·9 per cent. of total heat.	
45	40,054, or 51·9 „	= 5·3 „	„
90	51,938, or 67·3 „	= 6·8 „	„

Which shows that from four to seven per cent., or from 1-25th to 1-15th of the total heat, is all that is utilised

This is, in fact, the efficiency of the steam-engine working by the non-expansive, non-condensing process, in which steam is admitted for the whole of the stroke. Even the calculation of this fifteenth or twenty-fifth part is based on too favourable an estimate, as applied to such engines in their ordinary condition, because there is usually an element of loss of steam by partial condensation. The above comparative values, however, indicate clearly enough that a gain of efficiency is realised by the adoption of a higher pressure of steam, acting against the resistance of the atmosphere.

The Work of Steam without Expansion, but with Condensation.

After the piston, Fig. 118 (page 274), has been raised through the height due to the volume of steam generated against the pressure of the atmosphere, let the steam within the cylinder be condensed, and a vacuum be so formed. The resistance of the steam to the atmosphere being thus removed, the piston is free to descend under the atmospheric pressure of 2,116·8 lbs., and to raise a weight, B, over a pulley, D, equal to the atmospheric pressure, through a height equal to the descent of the piston. This additional work, obtained by condensing the steam, is equal to the work at first expended in repelling the atmosphere; and the total heat converted into work, exemplified at page 278, is utilised.

Even so, there is only from 7½ to 8 per cent., or about one-thirteenth of all the heat given to the boiler in generating steam, converted into useful work on the piston.

CHAPTER XXI.

THE PERFORMANCE OF STEAM WORKED EXPANSIVELY.

Steam, in its ordinary condition as saturated steam, though it does not rank as a perfect gas, nevertheless acts in the cylinder of a steam-engine so much to the same effect as a perfect gas could do, that its performance may be treated in the same way as if it were perfect as a gas. The quality in consideration of which a gas is said to be perfect is, as has already been stated, its property of expanding into a larger volume in the same proportion inversely as the pressure falls, the temperature being supposed to remain the same. Now, though saturated steam does not and cannot exactly follow this ratio, seeing that the pressure falls more rapidly than the volume increases, yet it is found that the work performed by steam by expansion in the cylinder of an engine is practically the same as if it acted on the principle of a perfect gas.

With this explanation, the curve described by the pencil of an indicator, indicating the falling pressure of dry saturated steam expanding behind an advancing piston, is, if not exactly, nearly hyperbolic in its nature, or such that the products of the pressures at all points of the stroke, multiplied by the respective volumes of the steam, are equal to each other.

As a ready means of calculating the work done by steam expanded in the cylinder, a table of hyperbolic logarithms is given (Table, No. 31). If there be supposed to be no clearance or lost space, at the end of the cylinder, then let the total work done by steam, during its admission into the cylinder, be represented by 1; the additional work done by expand-

TABLE No. XXXI.

HYPERBOLIC LOGARITHMS.

Num.	Hyp. Log.	Num.	Hyp. Log.	Num.	Hyp. Log.	Num.	Hyp. Log.	Num.	Hyp. Log.
1·05	·049	3·05	1.115	5·05	1·619	7·05	1·953	9·05	2·203
1·1	·095	3·1	1·131	5·1	1·629	7·1	1·960	9·1	2·208
1·15	·140	3·15	1·147	5·15	1·639	7·15	1·967	9·15	2·214
1·2	·182	3·2	1·163	5·2	1·649	7·2	1·974	9·2	2·219
1·25	·223	3·25	1·179	5·25	1·658	7·25	1·981	9·25	2·225
1·3	·262	3·3	1·194	5·3	1·668	7·3	1·988	9·3	2·230
1·35	·300	3·35	1·209	5·35	1·677	7·35	1·995	9·35	2·235
1·4	·336	3·4	1·224	5·4	1·686	7·4	2·001	9·4	2·241
1·45	·372	3·45	1·238	5·45	1·696	7·45	2·008	9·45	2·246
1·5	·405	3·5	1·253	5·5	1·705	7·5	2·015	9·5	2·251
1·55	·438	3·55	1·267	5·55	1·714	7·55	2·022	9·55	2·257
1·6	·470	3·6	1·281	5·6	1·723	7·6	2·028	9·6	2·262
1·65	·500	3·65	1·295	5·65	1·732	7·65	2·035	9·65	2·267
1·7	·531	3·7	1·308	5·7	1·740	7·7	2·041	9·7	2·272
1·75	·560	3·75	1·322	5·75	1·749	7·75	2·048	9·75	2·277
1·8	·588	3·8	1·335	5·8	1·758	7·8	2·054	9·8	2·282
1·85	·615	3·85	1·348	5·85	1·766	7·85	2·061	9·85	2·287
1·9	·642	3·9	1·361	5·9	1·775	7·9	2·067	9·9	2·293
1·95	·668	3·95	1·374	5·95	1·783	7.95	2·073	9·95	2·298
2·0	·693	4·0	1·386	6·0	1·792	8·0	2·079	10·	2·303
2·05	·718	4·05	1·399	6·05	1·800	8·05	2·086	15·	2·708
2·1	·742	4·1	1·411	6·1	1·808	8·1	2·092	20·	2·996
2·15	·765	4·15	1·423	6·15	1·816	8·15	2·098	25·	3·219
2·2	·788	4·2	1·435	6·2	1·824	8·2	2·104	30·	3·401
2·25	·811	4·25	1·447	6·25	1·833	8·25	2·110	35·	3·555
2·3	·833	4·3	1·459	6·3	1·841	8·3	2·116	40·	3·689
2·35	·854	4·35	4·470	6·35	1·848	8·35	2·122	45·	3·807
2·4	·875	4·4	1·482	6·4	1·856	8·4	2·128	50·	3·912
2·45	·896	4·45	1·493	6·45	1·864	8·45	2·134	55·	4·007
2·5	·916	4·5	1·504	6·5	1·872	8·5	2·140	60·	4·094
2·55	·936	4·55	1·515	6·55	1·879	8·55	2·146	65·	4·174
2·6	·956	4·6	1·526	6·6	1·887	8·6	2·152	70·	4·248
2·65	·975	4·65	1·537	6·65	1·895	8·65	2·158	75·	4·317
2·7	·993	4·7	1·548	6·7	1·902	8·7	2·163	80·	4·382
2·75	1·012	4·75	1·558	6·75	1·910	8·75	2·169	85·	4·443
2·8	1·030	4·8	1·569	6·8	1·917	8·8	2·175	90·	4·500
2·85	1·047	4·85	1·579	6·85	1·924	8·85	2·180	99·	4·554
2·9	1·065	4·9	1·589	6·9	1·931	8·9	2·186	100·	4·605
2·95	1·082	4·95	1·599	6·95	1·939	8·95	2·192	1000·	6·908
3·0	1·099	5·0	1·609	7·0	1·946	9·0	2·197	10,000·	9·210

ing the steam to the end of the stroke is represented by the hyperbolic logarithm of the ratio of expansion. The ratio of expansion is, if there be no clearance, expressed by the quotient obtained by dividing the length of the stroke by the period of admission. Adding the two quantities together, namely, the expressions for the work done during admission and that done during expansion, then the whole work done in one stroke is represented proportionally by

$$1 + \text{hyp. log. ratio of expansion.}$$

This expression shows the whole work done during admission to the cylinder, as well as during expansion for the remainder of the stroke, supposing the work done in admission is represented by 1. And, to find the total actual work done in any particular example, this expression has to be multiplied by the actual work done during admission. Suppose the cylinder to be 2 feet in diameter, with 5 feet of stroke, without clearance, and that steam of 50 lbs. pressure per square inch above the atmosphere is admitted on the piston during 15 inches of the stroke. The area of the piston is, by ordinary tables, 452·4 square inches; and this area, multiplied by 50 lbs. per square inch, gives

$$452{\cdot}4 \times 50 = 22{,}620 \text{ pounds}$$

as the whole of the pressure on the piston. The product of the whole pressure by the length in feet of that portion of the stroke during which the steam is admitted, expresses the total work done during admission, in foot-pounds, thus—

$$22{,}620 \text{ lbs.} \times 1{\cdot}25 \text{ feet} = 28{,}275 \text{ foot-pounds.}$$

Now the ratio of expansion is,

$$\frac{5}{1{\cdot}25} = 4;$$

that is to say, the steam is expanded four times, and the hyperbolic logarithms of 4 is, by the Table No. 31, 1·386; so that

$$1 + \text{hyp. log. } 4 = 1 + 1{\cdot}386 = 2{\cdot}386.$$

Finally, the product of 28,275 foot-pounds by 2·386, or

$$28{,}275 \times 2{\cdot}386 = 67{,}464 \text{ foot-pounds},$$

is the total work of the stroke, effected by the admission initially for a fourth of the stroke. It is to be observed that the work done by the steam initially has been increased to more than 2¼ times its amount by the simple act of expansion after the steam from the boiler ceased to flow into the cylinder.

The data for arriving at the comparative effects of expansive working may be otherwise obtained in terms of mean pressure. For this and for other data useful in calculations, connected with the work of steam in steam-engines, a useful Table, No. 32, compiled by Mr. David Thomson, is here given. It was communicated in an excellent paper on compound engines, read by him before the London Association of Foremen Engineers, in September, 1873.

To obtain the correct result by calculation of the effects of steam worked expansively in steam-engines, the amount of the clearance at each end of the cylinder should be taken into consideration.

TABLE No. XXXII.

Steam worked Expansively.

TABLE OF MEAN AND INITIAL PRESSURES IN THE CYLINDER. ON THE SUPPOSITION THAT THE PRESSURES ARE INVERSELY AS THE VOLUMES.

Points of Cut-off in fractions of the stroke, reckoned from the beginning.	Degrees of Expansion or number of times the steam is expanded.	Hyperbolic Logarithms of the Degrees of Expression.	Mean Pressures during the Stroke, the initial pressures being taken as 1.	Initial Pressures in Cylinder, the mean pressures being taken as 1.
$\frac{3}{4}$	$1\frac{1}{3}$	·2876	·965	1·036
$\frac{7}{10}$	$1\frac{3}{7}$	·3506	·949	1·054
$\frac{2}{3}$	$1\frac{1}{2}$	·4055	·937	1·067
$\frac{6}{10}$	$1\frac{2}{3}$	·5108	·904	1·106
$\frac{1}{2}$	2	·6931	·846	1·182
$\frac{4}{10}$	$2\frac{1}{2}$	·9163	·766	1·305
$\frac{1}{3}$	3	1·0986	·669	1·495
$\frac{3}{10}$	$3\frac{1}{3}$	1·2040	·661	1·513
$\frac{1}{4}$	4	1·3863	·596	1·678
$\frac{2}{10}$	5	1·6094	·522	1·916
$\frac{1}{6}$	6	1·7918	·465	2·150
$\frac{1}{7}$	7	1·9459	·421	2·375
$\frac{1}{8}$	8	2·0795	·385	2·598
$\frac{1}{9}$	9	2·1972	·355	2·817
$\frac{1}{10}$	10	2·3025	·330	3·030
$\frac{1}{11}$	11	2·3979	·309	3·236
$\frac{1}{12}$	12	2·4849	·293	3·448
$\frac{1}{13}$	13	2·5649	·274	3·649
$\frac{1}{14}$	14	2·6391	·260	3·846
$\frac{1}{15}$	15	2·7081	·547	4·048
$\frac{1}{16}$	16	2·7726	·236	4·237
$\frac{1}{17}$	17	2·8332	·226	4·425
$\frac{1}{18}$	18	2·8904	·216	4·629
$\frac{1}{19}$	19	2·9444	·208	4·807
$\frac{1}{20}$	20	2·9957	·200	5·000
$\frac{1}{21}$	21	3·0445	·192	5·208
$\frac{1}{22}$	22	3·0910	·186	5·376
$\frac{1}{23}$	23	3·1355	·180	5·555
$\frac{1}{24}$	24	3·1781	·174	5·747
$\frac{1}{25}$	25	3·2189	·169	5·917

The hyperbolic curve of expansion, expressive of the falling pressure, relative to the increasing volume, is represented by C G, Fig. 119. The rectangle A B E F is supposed to be the section of a cylinder, having a stroke of 24 inches.

The diagram is divided into 24 parts, or inches of stroke; during six of these, that is 6 inches of stroke, or one-fourth, A C, the steam is admitted, and it is expanded during the remaining three-fourths, C E. Supposing that there is no clearance, the terminal pressure, G F, would be one-fourth of the initial pressure during admission; that is, it would be equal to the initial pressure, taken in this instance at 100 lbs. total pressure per square inch, multiplied by the period of admission, and divided by the length of the stroke, or

$$100 \times \frac{6}{24} = 25 \text{ lbs. per sq. in.}$$

the terminal pressure.

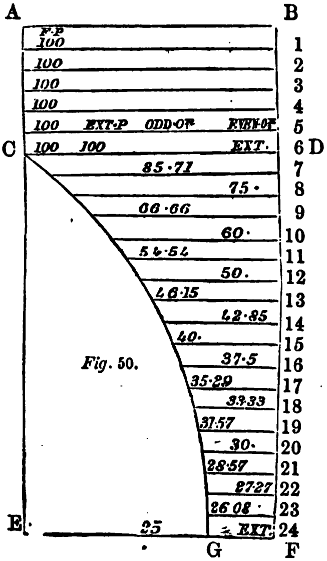


Fig. 119.

The pressure for any intermediate point of the stroke may be found, similarly, by taking the portion of the stroke described from the commencement to the given point, as the divisor. Thus, at the end of 15 inches of stroke the total pressure is

$$100 \times \frac{6}{15} = 40 \text{ lbs. per square inch.}$$

Finding the pressures, similarly, for each intermediate inch of the stroke, and drawing ordinates to the base B F, expressing the respective ordinates, for each inch of stroke; the curve may be formed by tracing it through the exties of the ordinates, as shown in the figure.

The process of finding the intermediate pressures is, in fact, a case of proportion; and the following statement, showing the proportional process for each of the ordinates, makes it quite clear :—

As 7 spaces : 6 spaces :: 100 lbs. press. : 85·71 lbs. press. at 1st expansive [ordinate
8 " : 6 " :: 100 " : 75· " 2nd "
9 " : 6 " :: 100 " : 66·66 " 3rd "
10 " : 6 " :: 100 " : 60· " 4th "
11 " : 6 " :: 100 " : 54·54 " 5th "
12 " : 6 " :: 100 " : 50· " 6th "
13 " : 6 " :: 100 " : 46·15 " 7th "
14 " : 6 " :: 100 " : 42·85 " 8th "
15 " : 6 " :: 100 " : 40· " 9th "
16 " : 6 " :: 100 " : 37·5 " 10th "
17 " : 6 " :: 100 " : 35·29 " 11th "
18 " : 6 " :: 100 " : 33·33 " 12th "
19 " : 6 " :: 100 " : 31·57 " 13th "
20 " : 6 " :: 100 " : 30· " 14th "
21 " : 6 " :: 100 " : 28·57 " 15th "
22 " : 6 " :: 100 " : 27·27 " 16th "
23 " : 6 " :: 100 " : 26·08 " 17th "
24 " : 6 " :: 100 " : 25· " 18th "

Having got so far, the work done by expansion may be calculated from these particulars without the aid of hyperbolic logarithms; and to simplify the operation, the area of the piston will be supposed to be 1 square inch, so that the pressures as given, per square inch, will be in fact the pressures on the piston. Dealing, first, with the initial pressure, it is 100 lbs. for 6 inches of the stroke; and its equivalent amount, if spread over the whole of the stroke, would be as much less in proportion as the stroke is greater than the period of admission. Therefore, if the initial pressure be multiplied by the period of admission, and divided by the length of stroke, the quotient is the pressure of admission averaged for the whole of the stroke, or

$$100 \times \frac{6}{24} = 25 \text{ lbs.}$$

This quotient, it may be noted, is the same as that which expressed the terminal pressure; showing that the initial pressure averaged for the whole of the stroke is equal to the terminal pressure.

In dealing with the varying pressure by expansion during the rest of the stroke, the average pressure during this period is found by adding together twice the sum of the intermediate pressures and the two extreme pressures, and dividing the sum total by twice the number of intervals, or twice the number of pressures, less 1. The intermediate pressures range from the end of the 7th inch to that of the 23rd inch, being 17 in number; and, with the extreme pressures, they make 19 in all, with 18 intervals. The sum of the intermediate pressures is 770·52 lbs., then,

770·52 × 2 = ...	1541·04
The extreme pressures { initial	100
{ final	25
The sum is	1666·04
Which, divided by (19—1) × 2 = 36,	
yields the quotient	46·3 lbs.

for the mean pressure during the period of expansion. To find the equivalent average pressure distributed over the whole stroke, that special average is to be multiplied by 18 and divided by 24: thus—

$$46{\cdot}3 \text{ lbs.} \times \frac{18}{24} = 34{\cdot}72 \text{ lbs.}$$

is the average expansive pressure for the whole stroke. Adding together this average and that of the initial pressure, we have—

Average initial pressure for the whole stroke .	25 lbs.
Ditto expansion ditto ditto .	34·72
	59·72 lbs.

This is the mean total pressure for the whole of the stroke.

What has just been done—the finding of the mean total pressure—for the sake of illustration, in two operations, may more briefly be done in one, by applying the rule of the ordinate pressures for the whole of the stroke together. The pressures at the end of the 1st, 2nd, 3rd, 4th, 5th, and 6th inches are each 100 lbs.; these added together make 600; and this added to the 17 pressures at the end of each inch, from the 7th to the 23rd inch, makes 1370·52: thus—

6 initial pressures of 100 lbs. each . . .	600
17 expansive pressures	770·52
23 ordinates	1370·52
Now 1370·52 × 2 = ...	2741·04
The extreme pressures { initial	100
final	25
The sum is	2866·04
Which, divided by (25−1) × 2 = 48, yields the quotient	59·71 lbs.

for the total mean pressure for the whole stroke—the same as was found by the double operation.

To check this result, the total mean pressure may be calculated by the agency of hyperbolic logarithms. The ratio of expansion is 4, of which the hyperbolic logarithm is 1·386, and

$$1 + 1{\cdot}386 = 2{\cdot}386.$$

The work done during the 6 inches or ·5 foot of admission, taking the area of the piston as 1 square inch, is

$$100 \times {\cdot}5 = 50 \text{ foot-pounds,}$$

and the total work done for the whole stroke is

$$50 \times 2{\cdot}386 = 119{\cdot}3 \text{ foot-pounds;}$$

dividing this work by the stroke in feet,

$$119{\cdot}3 \div 2 = 59{\cdot}65 \text{ lbs.}$$

the mean pressure per square inch, which differs by only ·06 lb. from the mean pressure already found by the method of the ordinates.

As a general rule for finding the total mean pressure that would be required to perform a given quantity of work, for one stroke of the piston, divide the whole work done in foot-pounds by the length of the stroke in feet, and by the area of the piston in square inches; the quotient is the total mean pressure, per square inch, for the whole of the stroke.

From the total work, and mean pressure, found as above, deductions are to be made for the resistance of back pressure, in order to find the effective mean pressure. The back pressure is usually taken at 2 lbs. per square inch on the piston, in condensing engines. For non-condensing engines, the deduction to be made comprises the resistance of the atmosphere, which may be taken as 15 lbs. per square inch, plus the resistance by back pressure of exhaust and compression, which *should not* be more than 2 or 3 lbs. per square inch; making together 17 lbs. or 18 lbs. per square inch.

CHAPTER XXII.

HORSE-POWER OF STEAM-ENGINES.

The nominal horse-power of non-condensing engines is commonly reckoned at the rate of 10 circular inches area of piston per horse-power. The calculation is easy:—Square the diameter of piston, and point off decimally the right-hand digit: the result is the nominal horse-power. For example, the piston of an engine is 12 inches in diameter; then $12^2=144$, and the nominal horse-power is 14·4 H. P. In some districts, 10 square inches of piston are allowed per nominal horse-power.

For condensing engines, the nominal horse-power is reckoned at the rate of 30 circular inches of area of piston per nominal horse-power. If the diameter of the piston in inches be squared, and the square divided by 30, the quotient is the nominal horse-power. For example, for a piston 36 inches in diameter, the nominal horse-power is

$$\frac{36^2}{30}=\frac{1{,}296}{30}=43{\cdot}2 \text{ H. P.}$$

The nominal horse-power of an engine, it will be seen, is not a direct measure of the power, but is only a commercial measure, having relation to the area of the piston, or the sectional area of the cylinder, by which engines are bought and sold. The actual horse-power, measured by the work developed in the cylinder, is much greater then the nominal power. The basis of an actual horse-power is the raising or moving of 33,000 lbs. weight, or resistance, through a height of 1 foot in one minute; that is to say, the performance of work at the rate of 33,000 foot-pounds per minute. To calculate the actual horse-power, therefore, the effective work done in the cylinder, in foot-pounds per minute, is divided by 33,000. The effective work is found for one stroke by multiplying the area of the piston in square inches by the effective mean pressure in pounds per square inch, by twice the length of stroke in feet, and by the number of turns of the crank-shaft in a minute. The whole process is compactly given by either of the following equations :—

$$\text{I. H. P.} = \frac{\text{Pressure} \times \text{area} \times \text{stroke} \times 2 \times \text{number of turns}}{33{,}000}, \text{ or}$$

$$\text{I. H. P.} = \frac{\text{Pressure} \times \text{area} \times \text{speed of piston in feet per minute.}}{33{,}000}$$

Take, for a comparison of the horse-powers computed by the two methods, the instance of the cylinder, Fig. 119, supplied with steam of 100 lbs. total pressure per square inch, and worked without condensation. The nominal power in turns of the diameter, which is, say, 15 inches, is

$$\frac{15^2}{10} = \frac{225}{10} = 22{\cdot}5 \text{ N. H. P.}$$

To find the actual or indicator horse-power :—the effective pressure is 59·65 lbs., less, say, 17 lbs. per square inch of back pressure, or 42·65 lbs. per square inch effective mean pressure. Let the number of turns be 90 per minute, equivalent to a speed of piston of 2 ft. × 2 × 90 = 360 ft. per minute; then the indicator horse-power is

$$\frac{42{\cdot}65 \text{ lbs.} \times 176{\cdot}7 \text{ square inches} \times 360 \text{ feet}}{33{,}000} = 82{\cdot}21 \text{ I. H. P.}$$

In this instance the horse-power actually developed in the cylinder is nearly four times as much as the nominal power.

Although in the example of a model indicator-diagram, Fig. 119, the stroke has been divided into 24 parts, the work done may be calculated from the diagram with a sufficient degree of accuracy, in almost all cases, when divided into only 10 equal parts.

CHAPTER XXIII.

COMPOUND STEAM-ENGINES.

COMPOUND engines are such as have two or more cylinders connected to one shaft, within which the steam works, consecutively from one to another. Steam is admitted to the first cylinder, where it may be partially expanded; and when the first piston arrives at or near to the end of the stroke, the steam is exhausted from the first into the second cylinder, within which it expands behind the second piston during its next stroke. The steam from the second cylinder may be further worked expansively in a third cylinder, but it is most commonly exhausted from the second cylinder into the condenser.

The steam which is exhausted into the second cylinder reacts upon the first piston, by back pressure, during its return stroke: it follows that if the second cylinder had only the same diameter and stroke as the first cylinder—in fact, if it had the same capacity—there would not be any expansive action of the steam so exhausted, as it would simply pass from one cylinder into the other, and there would not be any useful work done; the work done by the positive pressure on the second cylinder being equal to the opposing work done on the first piston by the back pressure. To generate useful work, therefore, in exhausting steam from the first into the second cylinder, the second cylinder must be of greater capacity than the first, either in having a greater diameter or a larger stroke, or both together, in order that the steam from the first cylinder may *expand* in the second, in virtue of the enlargement of volume which follows from the transference. Still, however, there is a resistance by back pressure on the first piston in the process of expansion; and as this is the same, or nearly the same, pressure per square inch both ways—on the second piston and on the first piston—it follows that the useful work done by expansion from the first into the second cylinder, supposing the strokes to be equal, is that due to the difference of the areas of the pistons.

Generally, looking to the increase of volume by expansion between the first and second cylinders, the work of the steam in this, the second stage of its operation, is simply that due to the number of times the final volume in the first cylinder is contained in the final volume of the second cylinder; in other words, to the ratio of expansion in the second cylinder. If there be no expansive working of steam in the first cylinder, so that the whole of the expansion is done in the second cylinder, then the proportional work or efficiency of the steam is to be calculated on the ratio of the volume of the second to that of the first cylinder. But if the steam be cut off in the first cylinder before the end of the stroke, then the total ratio of expansion will be that of the partial expansion in the first cylinder multiplied by the ratio of the volume of the second to that of the first cylinder.

For example, let the areas of the first and second cylinders be in the proportion of 1 to 4, the strokes being equal, then the ratio of expansion from the first into the second cylinder is 4. Let the steam be cut off in the first cylinder at half-stroke, or so as to expand it to twice its initial volume when the stroke is completed, then the ratio of expansion in the first cylinder is 2. Thus the total combined expansion of the steam in the two cylinders is $4 \times 2 = 8$ times the initial volume, and the ratio may be compactly stated thus:—

Expansion in first cylinder	1 to 2
Ditto in second ditto	1 to 4
Total combined expansion	1 to 8

Now, in this instance, by means of two cylinders combined, it appears that a total expansion of 8 times is effected, although the greatest in either cylinder individually is only an expansion of 4 times. In this reduction of the extreme of expansive working in any individual cylinder is to be found the source of the advantages of working steam by compound engines. It has already been stated (page 268) that attempts at increasing the performance of steam by expansive working are baffled by the variation of temperature of steam expanding in a cylinder. The temperature of steam falls with the pressure, and the cylinder is cooled to a certain extent by the end of the stroke. When the next charge of steam of the higher pressure is introduced for the next stroke, a part of it is condensed upon the cooler walls of the cylinder, which require to be heated to the temperature of the steam. This is a direct loss. True, the steam so condensed is partially resuscitated towards the end of the stroke by the heat which is partially returned from the cylinder to the expanding steam, when the temperature of this steam falls. Nevertheless, the absolute loss is so serious as to nullify attempts at usefully expanding steam beyond limits of about four times in one cylinder. Hence the advantage of dividing the expansion of steam between two cylinders, and thus reducing the range of the injurious variation of temperature in any one cylinder.

The second advantage of compounding engines is that the range of the variation of the pressure is, like that of the temperature, divided between two cylinders, and that, therefore, the pressure and blows to which the parts of the engine are subjected by the initial impulse of steam on the piston are also reduced. A compound engine is universally acknowledged to be a "sweet" working engine.

The following analysis of the action of steam in two compound cylinders with reference to the illustration, Fig. 120, reproduced from the first edition of this work, shows one way of treating the question:—Let Fig. 120 represent two such cylinders, of which the smaller, A, is 6 cubic feet in capacity, and the larger, B, of 24 cubic feet capacity, or in the ratio of 1 to 4. The first cylinder, A, receives the steam, say of 40 lbs. pressure per square inch, from the boiler, and the second cylinder, B, receives the steam, as indicated by the respective arrows, from the cylinder, A, after it has done its duty in that cylinder. Now, as the area of the larger cylinder is four times that of the smaller one, it follows that the steam expands to four times its volume in the larger cylinder, with a pressure corresponding to the diminution of force; and whilst the communication between the two cylinders is open, there is the same pressure in both cylinders, consequently the effective pressure in the larger cylinder is only on the three-fourths of its area by which it exceeds the smaller one.

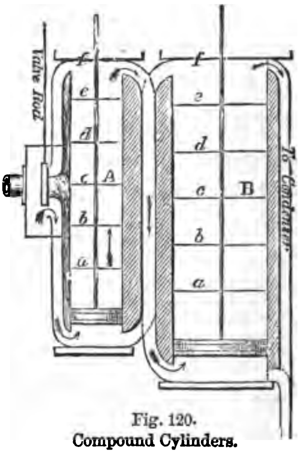


Fig. 120.
Compound Cylinders.

As has been seen, the pressure of elastic fluids is inversely as the space they occupy; if we suppose these cylinders divided into, say, six equal parts, 1, 2, 3, 4, 5, 6, it will sufficiently illustrate the comparative force of two cylinders.

For a constant quantity we have the capacity of the smaller cylinder, as 6 cubic feet, to be expanded into 24 cubic feet, and also fill the passages, say six-tenths of a foot, between the cylinders. If the pistons be moved through one-sixth of their stroke to *a a*, the pressure would be as under—

IN SMALL CYLINDER.						IN LARGE CYLINDER.				
Full pres. c. ft.		Empty space. c. ft.		Space still filled. c. ft.		Space filled. c. ft.		Passages. c. ft.		Steam expanded to fill. c. ft.
6	—	0	=	0	+	0	+	·0	=	6· initial
6	—	1	=	5	+	4	+	·6	=	9·6 for *a a*
6	—	2	=	4	+	8	+	·6	=	12·6 for *b b*
6	—	3	=	3	+	12	+	·6	=	15·6 for *c c*
6	—	4	=	2	+	16	+	·6	=	18·6 for *d d*
6	—	5	=	1	+	20	+	·6	=	21·6 for *e e*
6	—	6	=	0	+	24	+	·0	=	24·6 for *f f*

Taking the force of steam as 40 lbs. per square inch, the pressures for the respective ordinates of expansion, in double and single cylinder engines, would then be inversely—

	Expanded space.		lbs.		Orig. space.		In dbl. cylin. lbs.	Expanded space.	In single cylin. lbs.
Initial in first cylin.	6·	:	40	::	6	:	40·	none	40·
Initial in second cylin.	6·6	:	40	::	6	:	36·36	between the pistons	none
First space of expan.	9·6	:	40	::	6	:	25·	ditto, or *a a*	26·26
Second ,,	12·6	:	40	::	6	:	19·04	ditto, or *b b*	20·
Third ,,	15·6	:	40	::	6	:	15·38	ditto, or *c c*	16·
Fourth ,,	18·6	:	40	::	6	:	12·36	ditto, or *d d*	13·33
Fifth ,,	21·6	:	40	::	6	:	11·11	ditto, or *e e*	11·42
Sixth ,,	24·6	:	40	::	6	:	9·75	ditto, or *f f*	10·

The mean pressure may be found by the rules already submitted. For the large cylinder by hyp. log. it will be—

Exponent of expansion = 24·6 + 6 = 4·1, whose log. = 1·411 × 36·36 × 6·6 ÷ 18·6 (spaces to fill) = 18·2 lbs., nearly, as the mean pressure throughout the stroke on the large piston. On the smaller piston it would be 40 — 18·2 (the pressure on the larger piston) = 21·8 lbs.; hence, taking the value of the vacuum in the condenser as 12 lbs., for the power exerted we have the

Small cylinder area = 6 × 21·8 = 120·8
Large cylinder area = 24 × 18·3 = 436·8
Condenser vacuum = 24 × 12·0 = 288

Total power . . = 845·6 ÷ 24 = 35·23 lbs. mean pressure.

Out of this 845·6 lbs. of accumulated power, 288 lbs., or one-third of the whole, is due to the vacuum in the condenser, and 557·6, or two-thirds, to the steam.

It may be instructive to compare the power given out in a single cylinder of the same capacity, and using the same quantity of steam. Thus, hyp. log. of 4·1=1·411×40×6÷18·6 =17·67 lbs. as the mean pressure of expansion.

And as before—

Full pressure area	=	6	×	40	=	240·00
Expended pressure area	=	18·6	×	17·67	=	328·66
Condenser vacuum	=	24·6	×	12·0	=	295·20
Total power . .					=	863·86 ÷ 24 = 35·99 lbs. mean pressure.

Now 863·86 — 845·6=18·26 lbs., or 2·16 per cent. in favour of the power given out on one cylinder; but with this greater power there is also much greater irregularity of motion. For various classes of machinery now driven by steam such irregular motion would be highly detrimental, whilst the more uniform motion produced by the double-cylinder engine enables the principle of expansion to be more extensively applied to general purposes than by the single-cylinder engine.

There are other modifications of the double or compound cylinder engine, where the cylinders are placed one on the top of the other, and differently arranged, so as to provide the utmost economy.

In his excellent paper on Compound Engines, before referred to, Mr. Thomson exemplifies the application of his Table of *Steam Worked Expansively* (see page 286, *ante*), as applied to compound marine engines. The passage is worthy to be reproduced here. In explanation, it should be stated that compound marine engines are constructed with an intermediate "receiver," or chamber, into which the steam exhausted from the first cylinder is stored, in readiness to be admitted at the right time into the second cylinder. The necessity for the receiver must be obvious, when it is considered that the pistons of the two cylinders are connected to cranks at right angles to each other, and that, consequently, at the time that the steam is exhausted from the first cylinder, just before its piston arrives at the end of its stroke, the second cylinder is not prepared to receive the discharge of steam from the first, since the second piston is half-way either up or down the second cylinder. A receiver, or reservoir, is therefore required for the purpose of holding the steam discharged from the first cylinder until the valve of the second cylinder opens to admit it to the second piston at the beginning of the stroke.

"When steam," says Mr. Thomson, "is expanded in the cylinder of a steam-engine, its pressure at any part of the stroke is very nearly inversely proportional to the volume it occupies. This is not exactly the case, but very nearly so, and in almost all indicator-diagrams it is found that the pressure is slightly greater than it ought to be by this rule. If, therefore, the size of a cylinder is calculated on the supposition that the pressure of the expanding steam is inversely as the volume, a slight error may be expected on what engineers often call the 'right side'—that is, the size will be slightly above what is strictly required.

"The Table is calculated on the supposition that this rule is accurate. To give an example of its application, let it be required to find the area of a cylinder to yield 100 I. H. P. with a maximum pressure of steam of 60 lbs. above the atmosphere, an expansion of six times, back pressure of 2 lbs. per square inch, and a piston speed of 300 feet per minute.

"Here the average pressure required on the piston to give this power =

$$\frac{33000 \times 100}{300} = 11,000 \text{ lbs.},$$

Next, maximum pressure of steam above the atmosphere . . . . = 60 lbs.
Add pressure of atmosphere 15

Maximum total pressure . 75 lbs.

"Referring to the Table, in the line for six times expansion we find that in these circumstances the average pressure over the whole stroke

$=75 \times \cdot465$ . . . . . $=$ 34·875 lbs.
Deduct back pressure . . . . . 2·000
And we have the mean effective pressure over
the whole stroke . . . . . 32·875 lbs.

"From which it follows that the area of the piston $=$

$$\frac{11000}{32\cdot875} = 335 \text{ square inches,}$$

and a table of areas of circles gives diameter of cylinder $=$ 20⅝ inches.

"When a high degree of expansion is effected in one cylinder, the maximum strain on the crank-pin is much larger than the average working pressure over the length of the stroke, as is very clearly shown by reference to the Table. To diminish this excessive strain is the object sought in employing two cylinders to work conjointly, the one receiving the steam from the other, and thus forming what we call a compound engine.

"If, in the example we have taken, the six times expansion had been carried out in two cylinders, the mechanical effect developed would have been exactly the same, and so also would have been the final pressure. It is readily seen that, if the final pressure is the same in both cases, and the quantity of steam used is also the same, the capacity of the large cylinder of the compound engine must be the same as that of the single-cylinder engine of the same power, and working with the same degree of total expansion. All that is necessary, therefore, in calculating the size of the large cylinder for a compound engine, is to calculate in the way we have already done the size of a single cylinder to develop the required power with the given initial pressure and the given amount of expansion. This will be the size required for the large cylinder of a compound engine to develop the given power, and the only use of adding a small cylinder to it is to moderate the maximum strain on the crank-pin and give a more equable development of power over the whole stroke of the piston. This being the object aimed at, it is best to make the size of the small cylinder such that the maximum strain on the crank-pin shall be the smallest possible under the given conditions. Dr. Pole shows, for the Woolf form of engine, that this is effected by making

$$\frac{\text{Area of small cylinder}}{\sqrt{\text{Degree of expansion}}} = \text{area of large cylinder.}$$

The rule, applied to the example we have already taken, would give—

$$\text{Area of small cylinder} = \frac{335}{\sqrt{6}} = 137 \text{ square inches, and}$$

$$\text{Diameter} = 13\tfrac{1}{4} \text{ inches.}$$

"The area of the small cylinder being thus calculated, it is to be understood that, to get the best result, half the expansion is to be effected in the small cylinder, and the remainder during expansion into the large cylinder. Thus, in the present instance, the steam is to be expanded 2·449 times in each cylinder, and 2·449 × 2·449 = 6, making 6 times expansion in all.

"For the marine compound engine, the area of the small cylinder is not so definitely fixed, because, the two pistons acting on different cranks, the object generally is to make the maximum strain of either taken singly a minimum. And, besides, the maximum strains of either piston can be considerably varied by altering the point of cut-off in the large cylinder. Nevertheless, Dr. Pole's rule for Woolf-engines will be found generally to give good results for the other form of engine also, and such as fairly correspond with the best practice. The assertion that the mechanical power developed is the same whether the expansion takes place in one or in two cylinders requires this qualification, that when two cylinders are used the arrangements must be such that none of the expansion takes place uselessly by the steam rushing into the passages, and so causing a sudden drop of the pressure, without doing any work on the piston. In the Woolf form of compound engine this condition has not hitherto been absolutely complied with, and in some engines of this type it is very far from being so. A considerable loss of effect is the consequence.

"The amount of this will be seen if we take an example, thus—

" Let the capacity of the small cylinder be $= 4$; capacity of the large one $= 16$; and the capacity of the steam-passage between them $= 1$, or the fourth part of the small cylinder. Suppose, further, that the maximum total pressure of the steam in the small cylinder $=$ 75 lbs., and that it is cut off at one-third stroke. With these data the expansion should be (if we disregard the effect of the intermediate passage) 3 times in the small cylinder and 4 times more in expanding into the large one; or $3 \quad 4 = 12$ times. But the actual operation would be this—

" First, the steam would be expanded 3 times in the small cylinder, thus reducing the pressure to

$$\frac{75}{3} = 25 \text{ lbs.}$$

On the exhaust-valve being opened the steam would rush out of the intermediate passage, and thus occupy a space$=4+1=5$, by which its pressure* would be reduced to $25 \times \frac{4}{5} = 20$ lbs.;

---

* "It is assumed here and in what follows that the passage is entirely empty. This should not be the case, for it should be filled with steam of a pressure equal to the final working pressure in the large cylinder. In practice, however, the drop of pressure is generally quite as great as it ought to be, on the supposition of the passage being empty; and if the theoretical effect of the supposed small steam pressure existing in the passage were taken account of in these calculations, it would only complicate them without producing any difference of practical consequence in the results arrived at."

and this part of the expansion being uselessly expended in friction, and producing no motion on the pistons, would be productive of no useful effect.

"The steam which now occupies a space $=5$ will, at the end of the large cylinder-stroke, occupy a space $=16+1=17$; thus having been expanded $\frac{17}{5}=3\frac{2}{5}$ times during its passage into the large cylinder. The total effective expansion in both cylinders is therefore $=3\times 3\frac{2}{5}=10\frac{1}{5}$ times, instead of 12 times, which it would have been but for the effect of the intermediate passage. The loss of efficiency thus caused is measured by the difference between

$$1+\text{Hyperbolic log. } 12 \text{ and}$$
$$1+\text{Hyperbolic log. } 10\tfrac{1}{5}\,;$$

that is, it amounts to $1\frac{3\cdot322}{3\cdot485}=1-\cdot953=\cdot047$ (or nearly 5 per cent.) of the whole efficiency of the steam when expanded 12 times in one cylinder. In many Woolf-engines, the loss of efficiency from this cause is greater than this, but it need not be so if the engines are well constructed, and, as I have already said, this defect may be diminished or entirely removed if Woolf-engines were made with intermediate receivers, and the steam cut off at the proper point of the stroke in the large cylinder, as is done in the modern marine engines."

In a subsequent part of the paper, Mr. Thomson shows that, even when a considerable drop in the pressure takes place between the first and second cylinders, in the reservoir, the loss of indicator-power due to that drop need not exceed 5 per cent.

CHAPTER XXIV.

DESCRIPTION OF STEAM-ENGINES.

It has been seen that the beam-engine was the form of engine matured by James Watt, and the beam has never ceased, since his time, to be a leading feature in the modern steam-engine. Stationary beam-engines are usually made with condensers, and the engines erected by Messrs. William Fairbairn and Sons, at the Saltaire Mills, near Bradford, typify many of the mill-engines of the day. The engines at Saltaire are arranged in two pairs, to obtain the requisite uniformity of action, and they are placed in two large engine-houses on either side of the front entrance to the buildings. They are supplied with steam from ten boilers placed below the level of the ground.

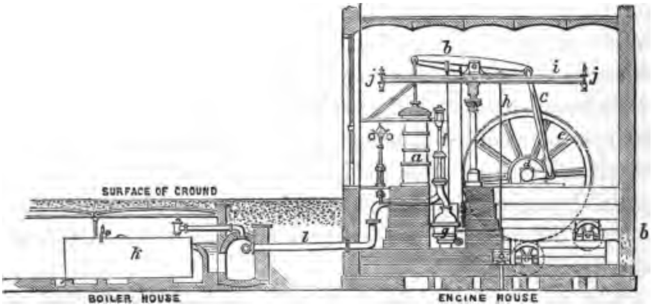


Fig. 121.—Engines and Boilers at Saltaire.

The engines and boilers are shown in side elevation, partly sectional, in Fig. 121. Steam, generated in the boilers, *k*, is brought through a prolongation of the tunnel, in which the smoke passes to the chimney, and enters the engine-house by the pipe *l*, which conducts it to the cylinder *a*, which is 60 inches in diameter, and has a stroke of 7 feet. Here the pressure of the steam is exerted on the piston within the cylinder, and transmitted through the working beam, *b*, to the large spur-wheel, *e*, 24 feet in diameter, from the circumference of which, at the lower part, the fórce of the steam is taken direct by pinions, which conduct it at the required velocity to the shafting of the mill. The working beam is supported on a pair of massive columns, 16 feet high, bolted down to the mass of masonry which constitutes the foundation of the engine. The entablature is bolted to each column, and to the columns of the adjoining engine, and is fixed in the walls of the engine-house on each side; the spring beams, *i*, over the entablature, and at right angles to it, are connected to the cross-beam, *j j*. Thus, a strongly fortified position is secured for the central bearings of the working beam, where the maximum stress of the engine is experienced. The spaces between the spring beams and the walls, except where the main beam vibrates, are floored with iron plates, approached by staircases, one of which is shown, over the cylinder. The beam receives its motion from the piston-rod, through the ordinary parallel motion, already illustrated at page 48, and transmits it through the connecting-rod, *c*, and the crank, *d*, to the fly-wheel, *e*.

The distribution of the steam in the cylinder is effected in the valve-chests, *f*, and the steam passes to the condenser, *g*, through the eduction pipe. The cold water is supplied to the condenser from a cistern. Beside the condenser is the air-pump worked by a rod from the working beam. A pump to supply the cold-water cistern is worked by the rod, *h*, and another pump is worked, by which hot water is supplied from the condenser to feed the boilers. The supply of steam to the engine is regulated by the governor, shown behind the cylinder, which acts on a throttle valve on the steam-pipe. The valve-chests, *f*, are fitted with equilibrum-valves, modifications of the double-beat or equilibrum-valve invented by Hornblower, and generally employed in the mining engines of Cornwall. The valves are moved by means of bevil gear driven by the crank-shaft. The double-beat valves consist of two discs, one a little smaller than the other, on the same spindle, which fit tightly on seats in the valve-casing. The steam in the casing presses on the outer sides of the valves, tending to keep close the upper valve and to open the lower valve. But as the upper valve is larger than the lower valve, and exposes a larger area than the lower, there is a proportional excess of pressure on the upper valve—the resultant pressure, in fact—which keeps the valves closed until they are lifted for the admission of steam, which passes from between them, into the cylinder. The force necessary to open the valves thus differentiated is only what is required to overcome the resultant pressure, instead of what would otherwise be the whole pressure on a single valve. The steam is likewise exhausted from the cylinder by double-beat valves. The steam is cut off by means of a variable cam at any point of the stroke required. The two engines of each pair are combined so as to act in concert upon the same crank-shaft, or main shaft, and fly-wheel, the cranks being placed at right angles to each other.

The power of each engine was estimated to be 100 nominal horse-power, according to the late Sir William Fairbairn's rule, which was, to multiply the area of the piston by 7 lbs. pressure per square inch, and by a speed of piston of 240 feet per minute, and to divide the product by 33,000. Thus, the area of piston being 1,963·5 square inches,

$$\frac{1963{\cdot}5 \times 7 \times 240}{33{,}000} = 100 \text{ N. H. P.},$$

giving 400 horse-power for the two pairs of engines.

The following particulars, with indicator-diagrams, of the performance of the Saltaire engines are quoted from the article *Steam Engine* in the "Encyclopædia Britannica," contributed by Mr. D. K. Clark:—The indicator-diagrams, Fig. 122, were taken from the engines when they were working at 25 revolutions per minute, and one pair with part of the load off. The maximum vacuum varied from 13 to 13·2 lbs. per square inch below the atmosphere; the average vacuum was 12¾ lbs. per square inch. Diameter of cylinder, 50 inches; area, 1963·50 square inches; speed of piston, 350 feet per minute.

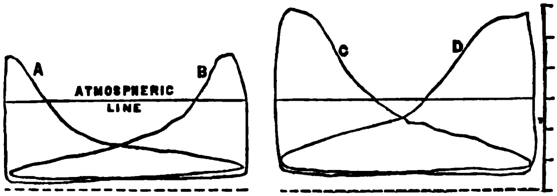


Fig. 122.—Indicator-diagrams from the Saltaire Engines.

From these diagrams we get—

lbs.

Engine A. Mean pressure of steam per sq. in. = 7·1684
Deduct for friction, air-pump, &c. = 2·0000

Effective pressure . . . = 5·1684

Actual horse-power = 107·63.

Engine B. Mean pressure of steam per sq. in. = 7·3646
Deduct for friction . . . = 2·0000

5·3646

Horse-power = 111·46.

Engine C. Mean pressure of steam per sq. in. = 13·301
Deduct for friction . . . . = 2·000

11·301

Horse-power = 235·34.

Engine D. Mean pressure of steam per sq. in. = 12·946
Deduct for friction . . . = 2·000

10·946

Horse-power = 227·95.

With a higher pressure of steam, however, or a shorter expansion, these engines will work to a considerably higher power.

The boilers for Saltaire have already been described at page 233. The draught is generated by a chimney 240 feet high. Each boiler was calculated at 50 nominal horse-power, allowing two-thirds of a square foot of grate per horse-power, and was said to be capable of supplying steam for 150 indicator horse-power. The consumption of fuel averaged from 3 lbs. to 3¼ lbs. of good coal per indicator horse-power per hour.

Compound Beam-Engines.

Mr. Wm. McNaught, of Manchester, introduced a second cylinder, as an addition to the ordinary beam-engine, placed under the beam on the crank side of the main centre. The two cylinders are worked as compound cylinders, the steam from the boiler being admitted first to the smaller cylinder, in which it is usually cut off at half stroke. Economy of fuel is effected by the addition of the extra cylinder, and Mr. McNaught has estimated that, after making a deduction for steam consumed in heating the mills, where his system has been applied, he has reduced the consumption of good coal to from 2 lbs. or 2¼ lbs. per indicator horse-power.

Beam-engines are occasionally compounded by placing two cylinders side by side under one end of the beam, exhausting from the top of the small cylinder into the bottom of the large cylinder, and *vice versâ*. On this system, illustrated by Fig. 123, the communications between the cylinders are more compact than in McNaught's arrangement, but

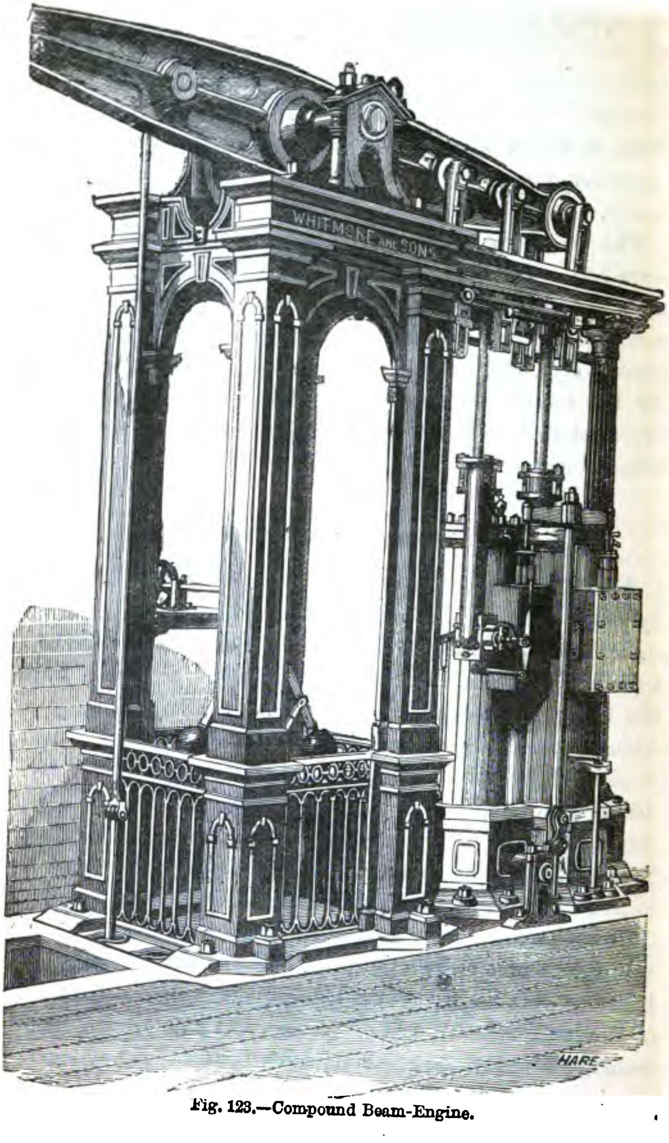


Fig. 123.—Compound Beam-Engine.

the stress on the beam and on the main centres is considerably greater, though it must be obvious that if two compounded cylinders side by side be substituted for a single cylinder, to develop equal power, the actual stress on the beam will be reduced.

Horizontal Engines.

Dispensing with the traditionary beam, most stationary steam-engines are now constructed as direct-acting, the piston-rod being connected direct to the crank, and the cylinder and shaft being contained in one base-plate. Thus a simpler, lighter, and less costly engine is obtained, and one which is equally efficient with the beam-engine. The engine, Fig. 124, exemplifies the general arrangement of single-cylinder horizontal engines, non-condensing; and a neatly finished example of a double-cylinder horizontal condensing engine, by the Reading Iron Works, is given in Fig. 125. This engine was designed with a view to highly expansive working. The cylinders are steam-jacketed, and each cylinder is fitted with a variable-expansion valve, superposed on the ordinary slide-valve, by which the steam may be cut off at one-tenth of the stroke. The piston-rods are prolonged through the covers of the cylinders, and work the air-pumps, which, together with the condenser and hot wells, are placed in line at the backs of the cylinders. The capabilities of the valve-gear for working the steam at a high rate of expansion are proved by the indicator-diagram, Fig. 126, taken from both ends of a single-cylinder engine constructed and arranged as in the figure. The cylinder was 21 inches in diameter, and had a 30-inch stroke, and was steam-jacketed at the sides and ends. Steam was cut off at 3⅛ inches of the stroke. The average speed of the engine was 60 revolutions per minute, giving a speed of piston of 300 feet per minute. The diagrams prove by calculation that 47 indicator horse-power

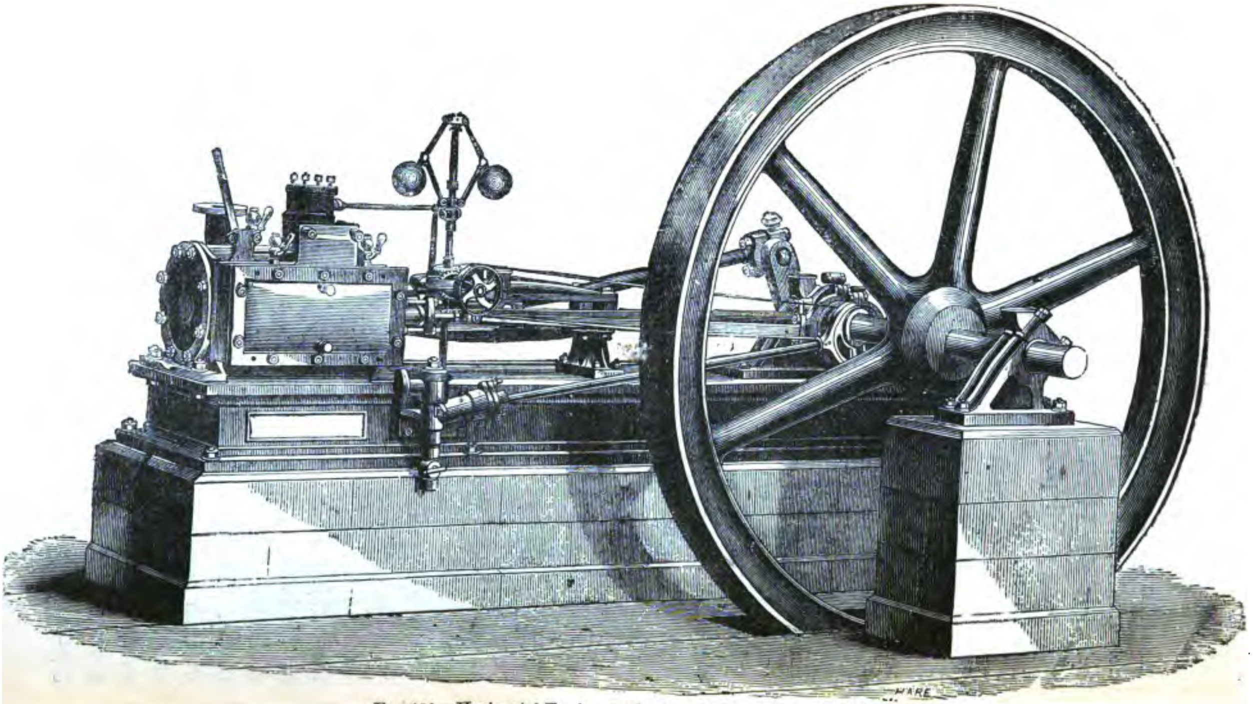


Fig. 124.—Horizontal Engine, with one cylinder, non-condensing.

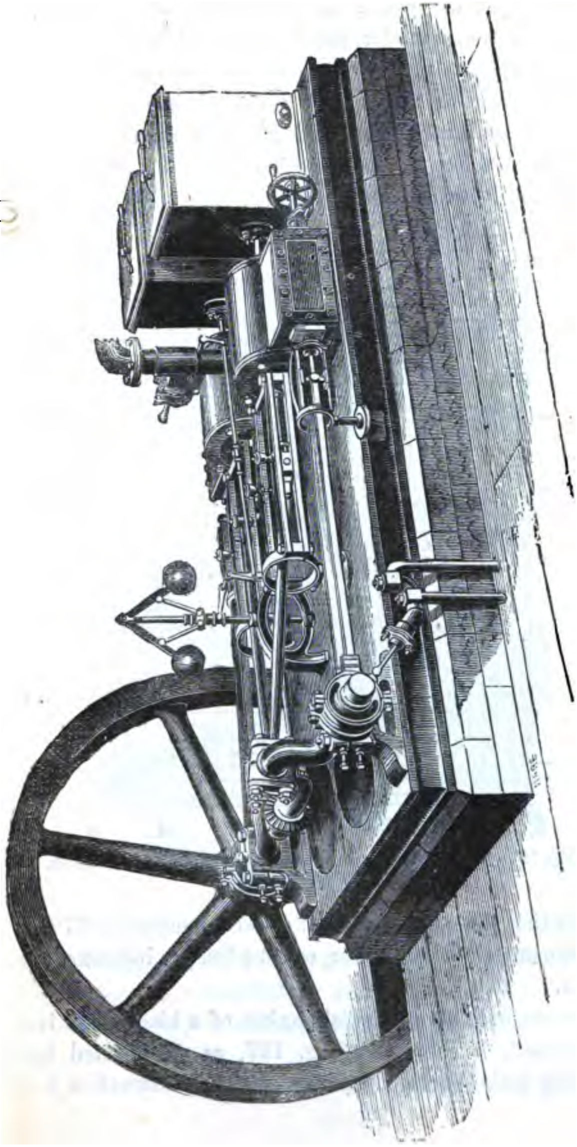


Fig. 125.—Horizontal double-cylinder Engine, condensing.

was exerted; the power at the crank-shaft, measured by means of a dynamometer, amounted to 40 horse-power; from which it appears that the resistance of the engine consumed 7 horse-power, or 15 per cent. of the whole indicator-power. The fuel consumed was 3·06 lbs. per dynametric horse-power, or 2·6 lbs. per indicator horse-power. As the boiler evaporated 9 lbs. of water from a temperature of 82° Fahr., it follows that the consumption of water amounted to 27·55 lbs. per dynametric horse-power, or 23·4 lbs. per indicator horse-power.

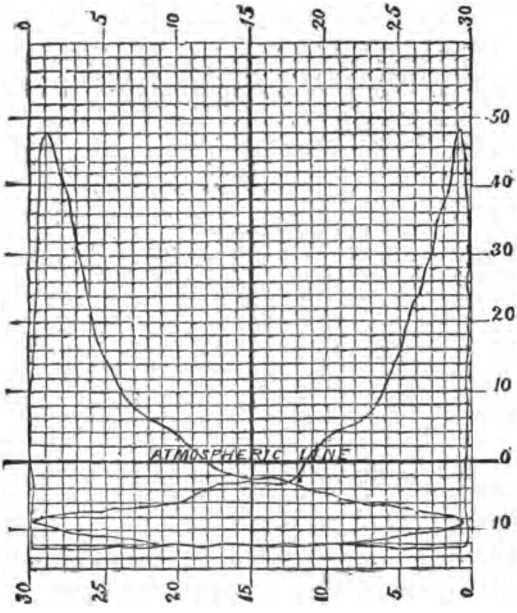


Fig. 126.—Indicator-diagram from a horizontal condensing Engine, by the Reading Iron Works.

An example of horizontal engine, of a kind which is now much used, is shown in Fig. 127, as constructed by the Reading Iron Works. The principle of construction is very simple. There are but two principal castings—the sole, with which the main plummer-block is cast in one piece, and the cylinder. The cylinder is overhung, and is united to the sole by one end, with a square joint. For small powers this system of construction, which has been adopted by various makers, is not only simple, but also strong and compact.

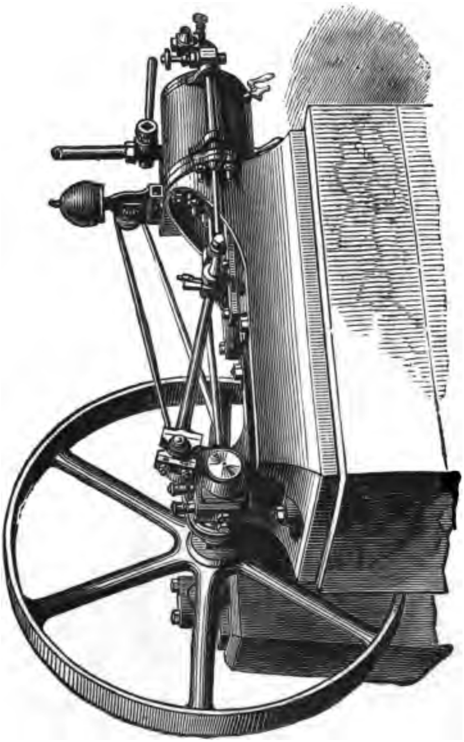


Fig. 127. Horizontal Engine, by the Reading Iron Works.

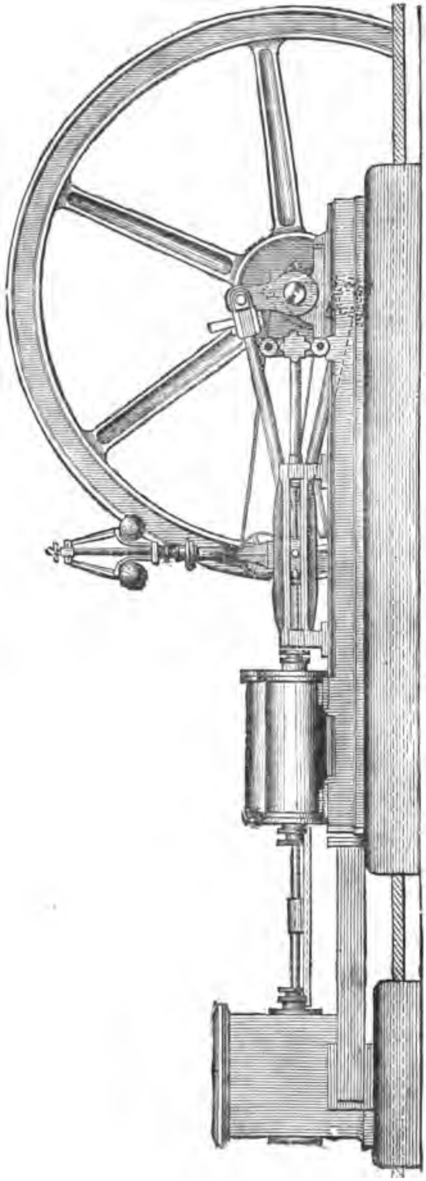


Fig. 128.—Horizontal Compound Engine. Elevation.

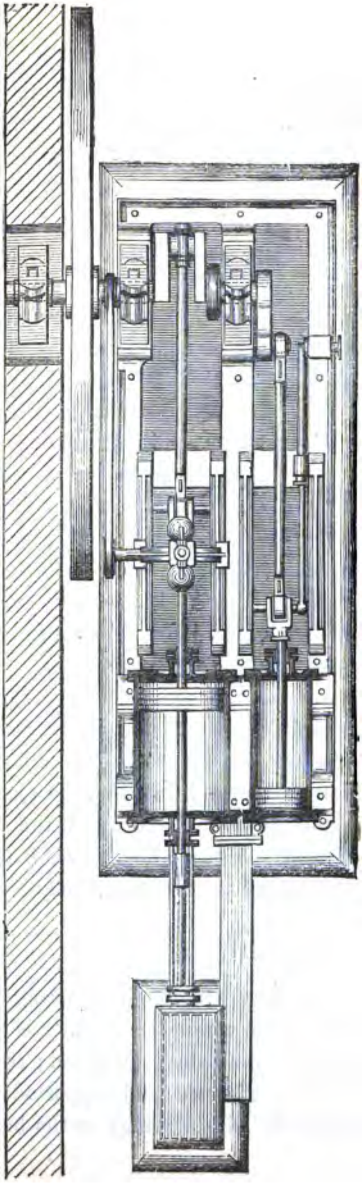


Fig. 129.—Horizontal Compound Engine. Plan.

Horizontal Compound Engines.

The horizontal arrangement offers great facility for the application of compound cylinders. An example constructed by the late firm of Carrett, Marshall, and Co. Figs. 128, 129, 130, has two cylinders, side by side, of which the smaller, and first, is 12½ inches in diameter; and the second is 21 inches in diameter, with a stroke of 27 inches. They are connected to one shaft with cranks diametrically opposed. The steam is distributed by means of a single slide-valve, by which the steam is exhausted directly across from the first to the second cylinder, through the shortest possible passage. Thus, also, the reciprocating mechanism is self-balanced. The air-pump, which is double-acting, and the condenser are placed apart, behind the low-pressure cylinder; the pump is within the condenser, and is worked by a prolongation of the piston-rod of the second cylinder.

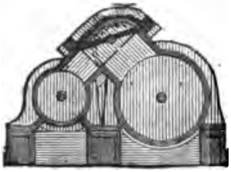


Fig. 130. — Horizontal Compound Engine. Section of Cylinders.

The sectional areas of the cylinders are as 1 to 3. In order to obviate simultaneously dead points in the revolution of the cranks, these are set, not precisely in a line, but at a slight angle, the larger piston being thereby placed slightly in advance of the position it would occupy if the cranks were exactly in line. The slide-valve, which serves both cylinders, has two faces, and the lead and the travel may be varied.

Vertical Steam-engines.

Engines known as vertical are direct-acting, and are of two classes: first, those in which the cylinder is fixed to the base, and works to the crank-shaft overhead; second, those in which the cylinder is inverted and supported above, and works to the crank-shaft, with bearings on the base.

Of the first class, Fig. 131 is an example, in which the whole engine stands on a bed-plate; a round column is placed beside the cylinder to carry the crank-shaft. The governor is placed on the top of the column, with a bearing

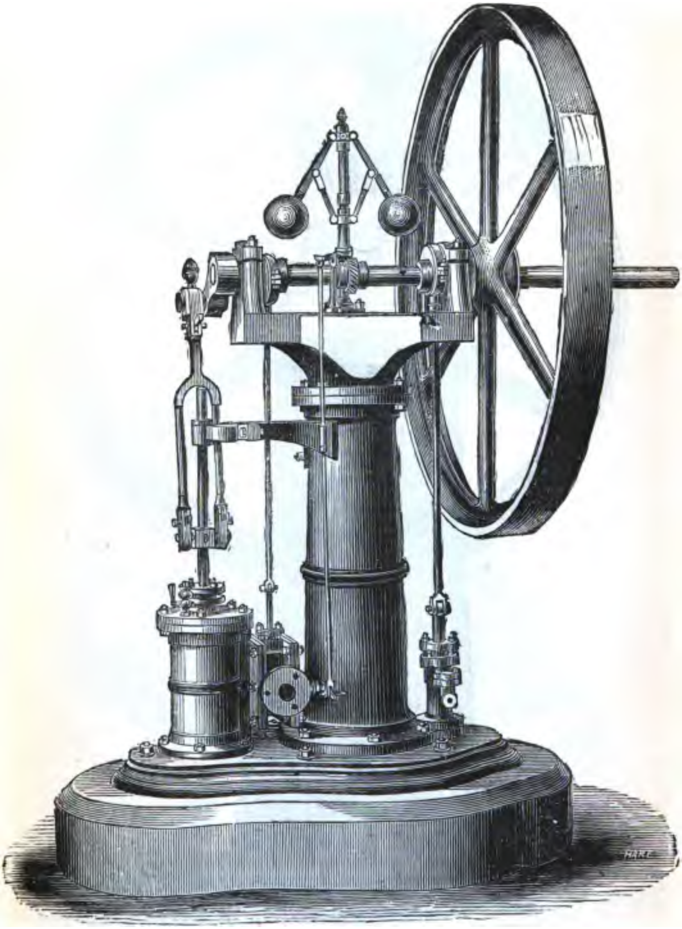


Fig. 131.—Vertical Steam-engine.

in a deep socket, and is compactly driven from the shaft by means of skew-gear.

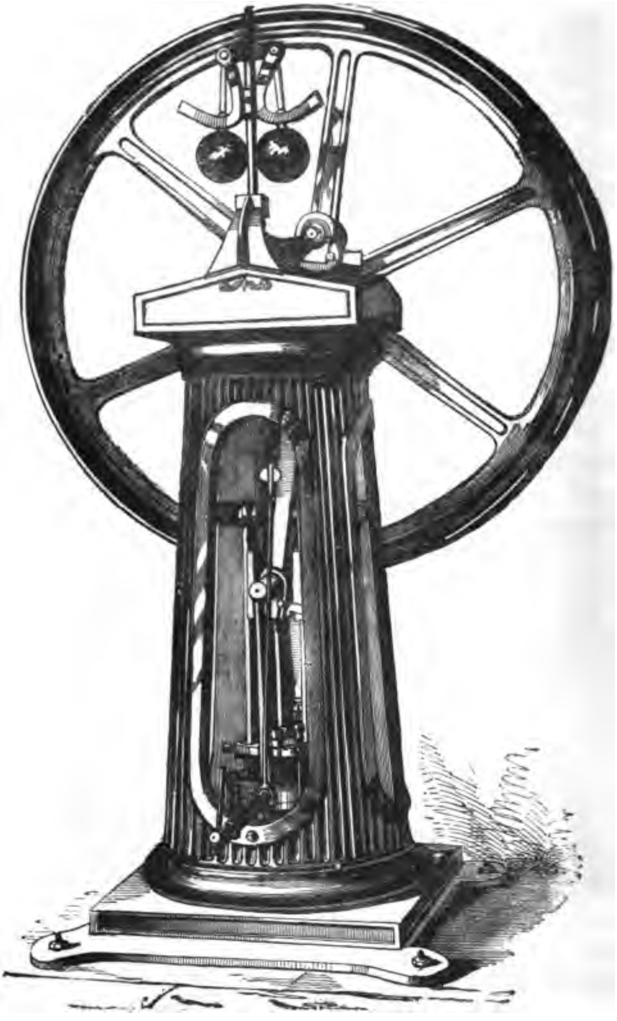


Fig. 182.—Vertical Steam-engine.

Another example is shown by Fig. 132, in which the cylinder is fixed within the base of a column, which is open at four sides, and answers the purpose of a frame, equally stiff in every direction. But the engine is rather too confined.

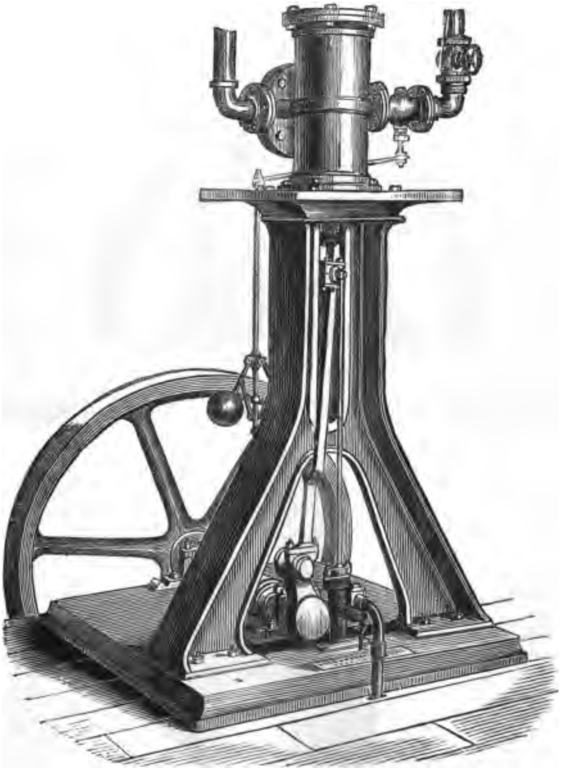


Fig. 133.—Inverted-cylinder Steam-engine.

Of the second class of vertical engines, with an inverted cylinder, Figs. 133 and 134 are examples. Such engines are appropriate where the main shaft is required to be low; but they have their inconveniences in the liability to leakage and droppings from the stuffing-box.

An arrangement of inverted-cylinder engine, fixed upon a vertical boiler, is shown in Fig. 135. This was designed for small powers, for the sake of compactness, by the late Messrs. Carrett, Marshall, and Co.

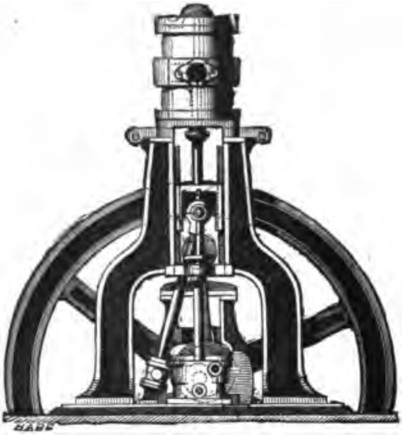


Fig. 134.—Inverted-cylinder Steam-engine.

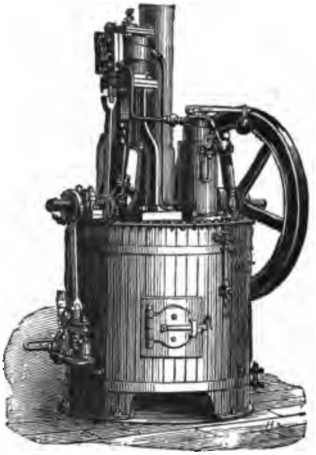


Fig. 135.—Inverted-cylinder Engine and Boiler.

Pumping Engines.

Pumping water from mines, or for the service of towns, or for other purposes, is the simplest mechanical duty performed by steam. The work is a direct lift, and may be done, and has generally been done, by the action of steam in a cylinder, single-acting, at one end of a beam, and the raising of the water by a pump-plunger, or pole, at the other end of the beam, as in the Cornish engine, illustrated by Fig. 136, showing in skeleton elevation one of the engines at the East London Waterworks. The steam-cylinder, A, is 100 inches in diameter. The pump, B, is a

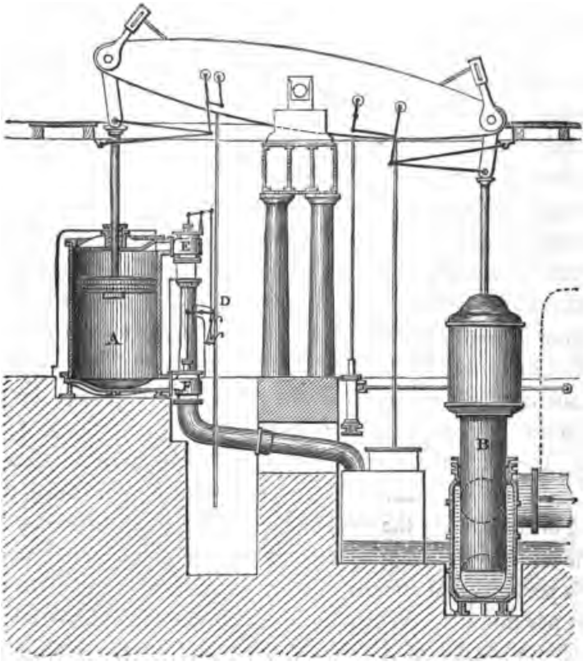


Fig. 136.—Cornish Pumping Engine.

plunger-pump, the pole, or plunger, of which is loaded with iron weights sufficient to counterpoise the pressure of a hydrostatic column, which is the measure of the pressure created in the central station to put in motion the supply of water to the consumers. The loaded plunger is lifted by the action of the steam in the cylinder, A, and is allowed to descend by gravity at a speed depending on the quantity of engine-power in action, and the rate at which the water is being drawn away. The chamber of the pump is filled by water when the plunger is raised, the water passing through the suction-valve at the side of the plunger. In engines worked on this principle,—in all reciprocating engines pumping without the intervention of cranks,—there is nothing to limit the strokes of the engine to any exact length. Bumpers, or catch-pieces, are therefore applied to restrain the engine at both ends of the beam from describing an undue length of stroke. The bumpers consist of thick plates of india-rubber under blocks of hard wood. The speed of the engine is regulated by an adjustable cataract; the exhaust valve first, and then the steam-valve, are thrown open by treadle-weights so soon as the catches are detached by the cataract. The valves are closed by tappets on a plug-rod, D,—first the steam-valve, E, and then the exhaust-valve, F. The steam-valve is closed at from a third to a fifth of the stroke; the exhaust-valve, at the end of the stroke. The stroke of the engine raising the load—the indoor stroke —is performed at a mean velocity of piston of from 500 to 600 feet per minute. When the steam is cut off at one-quarter stroke, a stroke of 10 feet is frequently performed in one second. The number of strokes varies from 4 to 10 per minute. The cylinder is cased in a steam-jacket, which is enveloped in an outer coating of ashes, 12 inches in thickness. The indicator-diagram, Fig. 137, was taken from the cylinder when the steam was cut off at one-quarter stroke; the length of stroke was 11 feet, and the total load on the piston was equal to 16·58 lbs. per square inch. The pressure in the boiler was from 30 lbs. to 35 lbs. per square inch above the atmosphere. In the diagram it is shown to have been 25 lbs. per square inch at the beginning of the stroke, and to have dropped to 13½ lbs. per square inch when the steam was cut off. This fall of pressure is due to the rapidly acquired velocity of the piston moving under the pressure of the steam, and the consequent wire-drawing of the steam in passing into the cylinder. At the end of the stroke the steam has expanded down to a pressure of 7½ lbs. per square inch total, or 7¼ lbs. below the atmospheric line. The equilibrium-valve being then opened, the steam above the piston is admitted to circulate freely under the piston, and thus equal pressures are established above and below it. This equality is indicated on the diagram by the junction of the upper and lower figures in one line of contact. The consumption of fuel is at the rate of about 2¼ lbs. of coal per indicator horse-power per hour. The "duty," or useful work done, measured by the quantity of water raised, is about 80 per cent. of the indicator power, and it is equivalent to about 80 millions of pounds of water raised one foot high for each hundred-weight of coals.

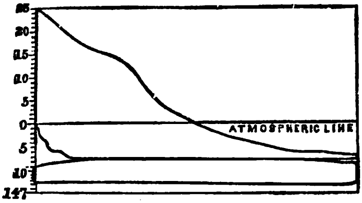


Fig. 137.—Indicator-diagram from Cornish Engine.

Rotative pumping-engines for waterworks—such as are double-acting, and are regulated by a crank and fly-wheel—have been employed to a considerable extent, and they advantageously compare with the single-acting Cornish engine in efficiency of performance.

A steam-pump and boiler in one are illustrated by Figs. 138, 139, 140, specially adapted for supplying water for fountains, railway stations, &c. The pump and engine, which are horizontal, are mounted upon a locomotive-boiler, which rests on

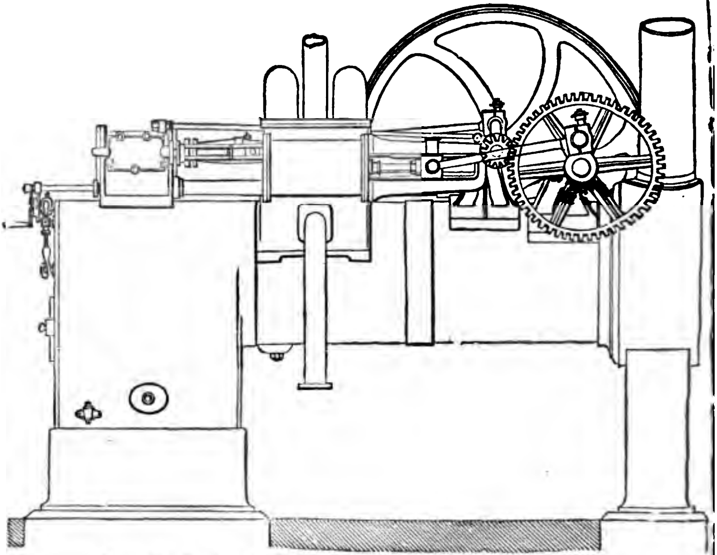


Fig. 138.—Semi-portable Steam-pump and Boiler. Side Elevation.

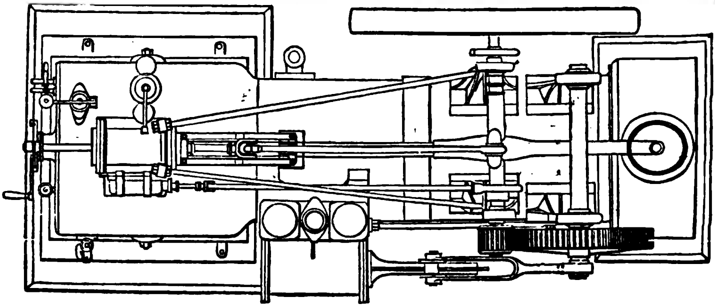


Fig. 139.—Semi-portable Steam-pump and Boiler. Plan.

two cast-iron pedestals. The speed of the engine is reduced by gearing to give the speed of the pump. This engine, rated as of three nominal horse-power, is capable of raising from 4,000 to 5,000 cubic feet of water 115 feet high in ten hours.

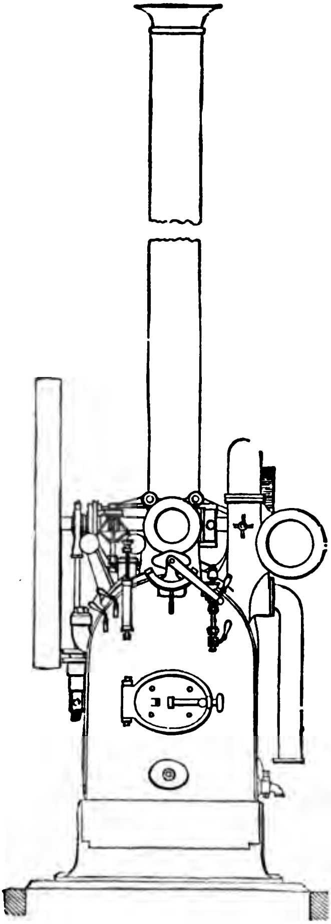
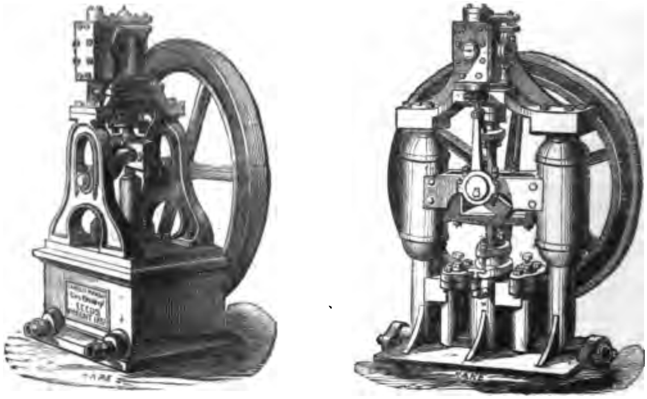


Fig. 140.—Semi-portable Steam Pump and Boiler. End Elevation.

Three varieties of a class of vertical pumps—donkey-pumps, as they are called—worked direct from a steam-cylinder, are shown in Figs. 141, 142, 143. Each of these has two air-vessels—one for the suction, and one for the delivery; so that the water is drawn in and forced out in a stream,



Figs. 141 and 142.—Vertical Donkey-pumps.

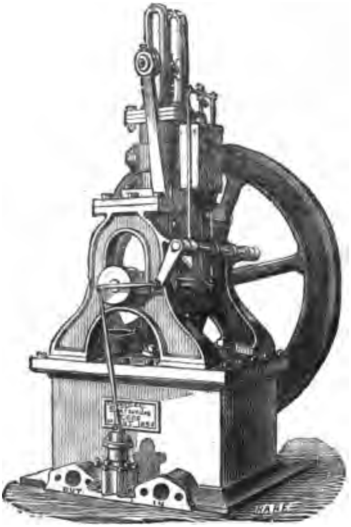


Fig. 143.—Vertical Donkey-pump.

nearly, if not quite, continuous, by the pump-ram, which is single-acting. By this means, the working of the engine is

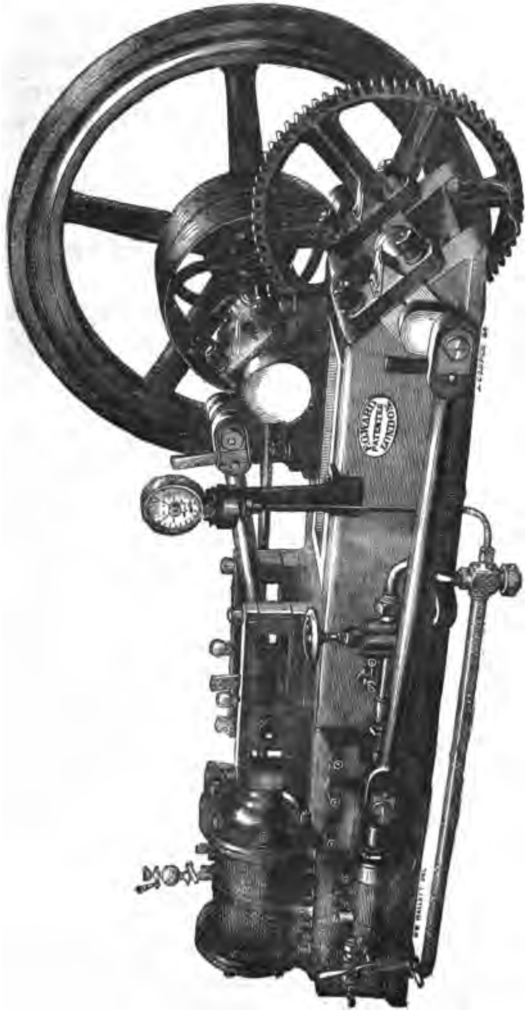


Fig. 144.—Double-acting Hydraulic Pumps.

independent of the distance from or to which the water may be fetched or forced, inasmuch as the water, being permitted to continue in motion in the pipes in one direction, is not stopped and started at every stroke. In the first and second pumps, the fly-wheel is driven by means of a slotted-frame movement; and in the third, side connecting-rods and guide-bars are used. The second pump is used for working against great pressures.

An arrangement of double-acting steam hydraulic pumps is shown by Fig. 144, designed by Mr. F. O. Ward. On a hollow bed, serving also as a cistern, are fixed a steam-engin and a system of force-pumps worked in pairs by connectin rods, the speed of the engine being reduced by intermedi gearing.

Portable Engines.

The demand for, and the use of, portable engines—that i engines which with their boilers are movable on wheels has arisen nearly altogether since 1851. They are speciall useful for supplying steam-power out of doors,—in the fiel for agricultural and other operations, and in the yard, for purposes where the power of horses has been employe Portable engines are usually of eight nominal horse-power, an are constructed with boilers of the locomotive type, with in side fire-box and flue-tubes; and the cylinder or cylinde (if two in number) are fixed on the top of the boiler at on end, and the crank-shaft at the other. Practically, th boiler constitutes the foundation, or base, of the whole structure. Fig. 145 is an average example of portable engines; the chimney being turned down over the boiler when not in steam.

The flue-tubes of portable-engines are of various diameter, from 1⅝ to 2¾ inches in diameter outside, and from 5 feet to 7½ feet long; and they vary from 35 to 80 in number. The area of fire-grate varies from 3 to 7 square et, and the heating surface from 160 to 280 square feet.

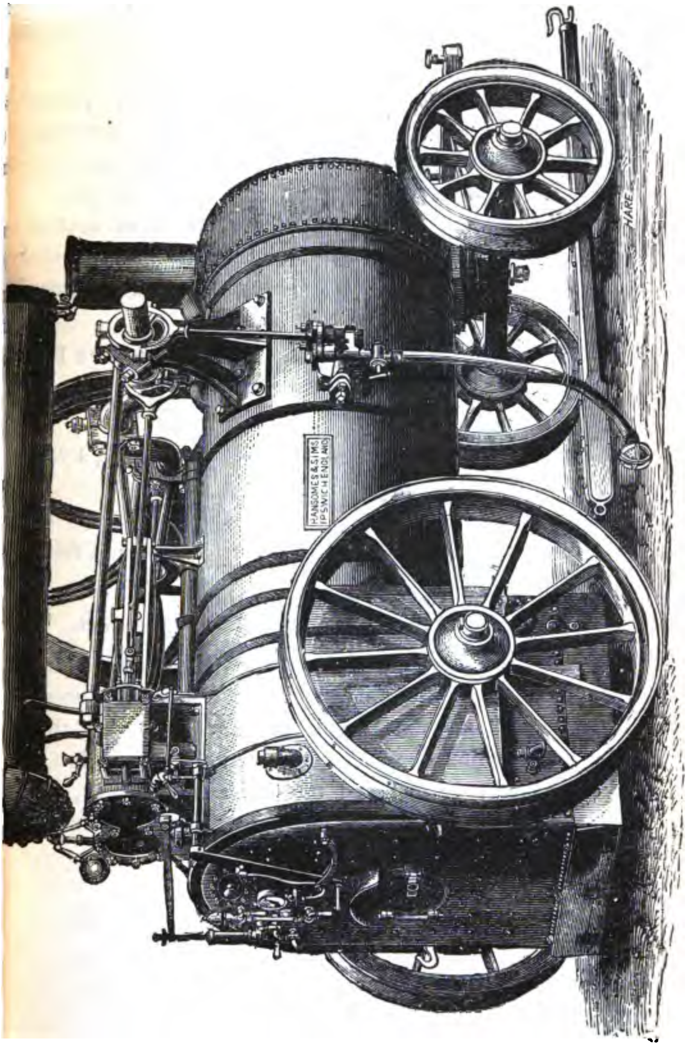


Fig. 145.—Portable Engine.

The cylinders vary from 7¼ to 9½ inches in diameter, and from 12 to 14 inches stroke; they are generally steam jacketed. The pressure in the boiler is in general 80 lb per square inch, though 120 lbs. has been used. The engin weighs (empty) from 3¼ to 4 tons.

The improvements that have been made in portabl engines since 1851, both in construction and in economy o fuel, are remarkable. The results of the performance o engines in that year have already been given at page 83 In the trials of the portable engines which were tested i 1872, at the Exhibition of the Royal Agricultural Society, at Cardiff, the following were the average general result arrived at:—

Indicator horse-power	9·1 to 24·8 I.H.P.
Dynametric horse-power, at fly-wheel shaft, ratio to indicator horse-power	82¾ per cent.
Coal (Langennech) consumed per indicator horse-power 2·38 to 4·94 lbs.;	average, 4·02 lbs.
Coal per square foot of grate per hour	17·6 lbs.
Water as supplied and evaporated at 212° F., per lb. of coal	9·85 lbs.
Heating surface per indicator horse-power	13 square feet.
Steam consumed per indicator horse-power	32·5 lbs.
Proportion of heat-value of work done at the brake to the total heat-value of the coal	4½ per cent.

The instructive lessons of the portable engine prove clearly the vital importance of thoroughly protecting the steam-cylinders by steam-jackets or lagging, or both. To these appliances, in conjunction with expansive working, are due the marked economy of fuel, and the increased efficiency, with which the most recent portable engines perform their duty.

Traction-Engines.

Traction-engines were originally devised to supersede horse-power on common roads, previously to the general adoption of railways for purposes of transport. The railways set them aside for a time; but within the last fifteen or twenty years the employment of traction-engines has been evived. It has been established that, on the best ordinary oads, the heaviest loads can be drawn with greater economy y steam-power than by horse-power; and that, in ascending r descending the steepest hills, or in passing over soft and marshy ground, where no roads exist, traction-engines have taken loads which could not have been transported by any available number of horses. Traction-engines are commonly

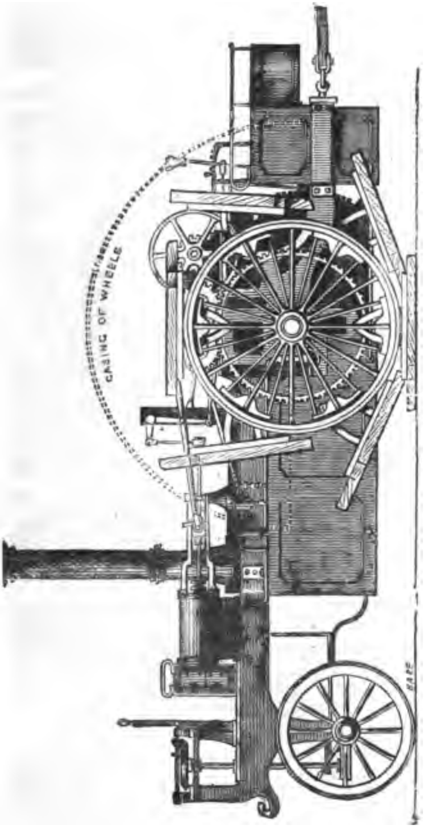


Fig. 146.—Boydell's Traction Engine.

fitted with two speeds—fast and slow—one or other of whic may be put in gear, according to the load and the roa They are also fitted with steering apparatus, applied to th

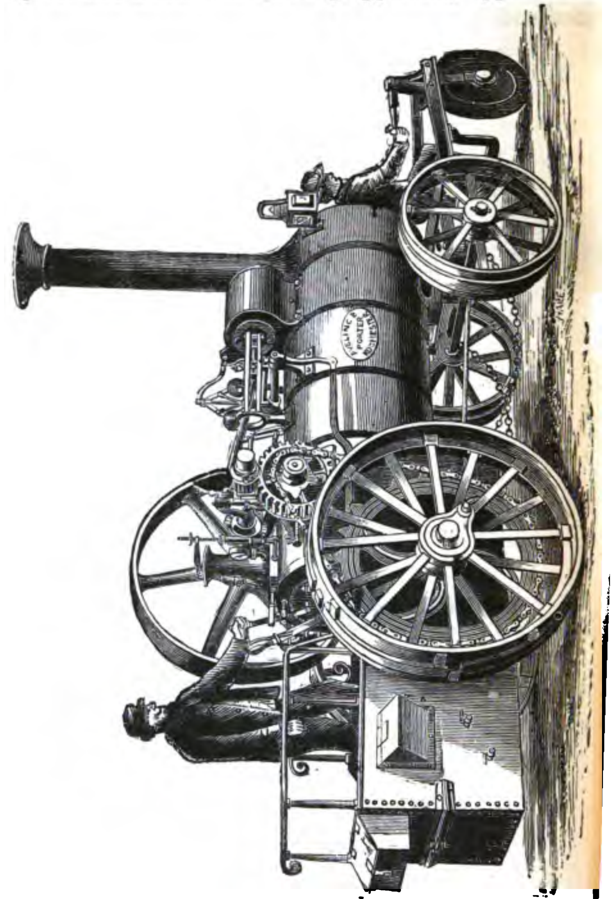


Fig. 147.—Aveling's Traction-Engine.

fore wheels. Like portable engines, they are made wi locomotive-boilers.

Boydell's traction-engine, Fig. 146, was constructed with an "endless railway," being a system of wooden trams or shoes hung round each wheel, which are successively laid down on the ground for the wheel to advance over them, and lifted after the wheel is past. As the shoes were broad and flat, they afforded a greater bearing for the wheel than could be commanded by wheels which ran directly on the ground. The tear and wear of the trams was so great as

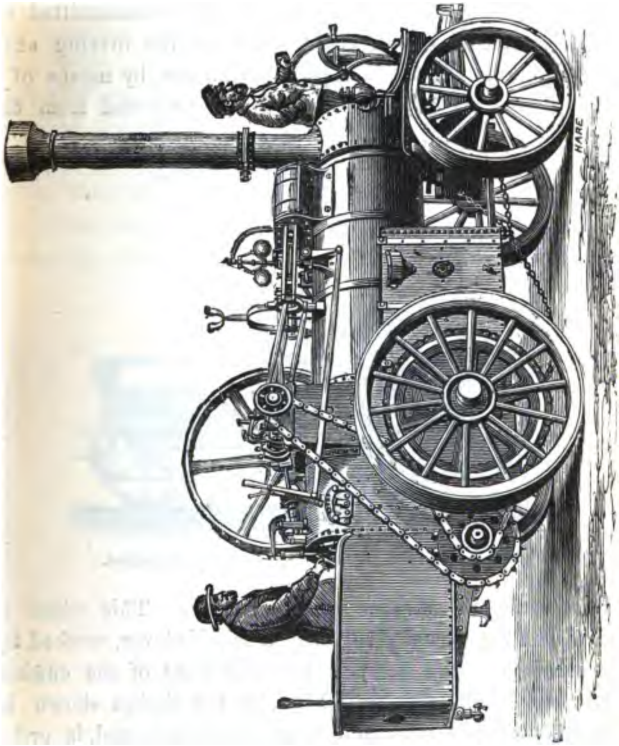


Fig. 148.—Robey's Traction Engine.

to lead to the abandonment of this system for traction engines.

The traction engine of Messrs. Aveling and Porter, Fig. 147, has but one steam-cylinder, placed on the top of the boiler. The crank-shaft is connected to the driving-wheels with but one speed, by means of an intermediate shaft with toothed gearing, from which the motion is transmitted by an endless chain over a chain wheel on the driving axle. The engine is steered in a peculiar manner, by means of a single disc wheel in a triangular frame, projected from the leading axle, in advance of the engine. This wheel is swivelled on a central pivot, with a suitable lever, worked by the steersman, who occupies a seat in front of the engine. The rims of the driving wheels, in the design shown in Fig. 147, which are of cast iron, are deeply indented, in order to afford the necessary grip for propulsion. In some recent designs, the rims of the wheels are made of wrought iron, with strips of the same material riveted on the circumference, diagonally across.

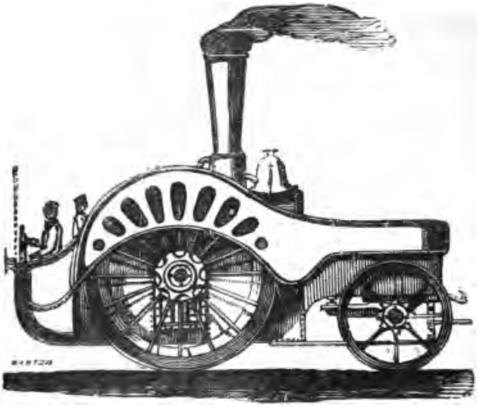


Fig. 149.—Taylor's Steam-Elephant Traction-Engine.

In the traction engine, Fig. 148, by Messrs. Robey and Co., the driving-wheels are driven by means of two pairs of pitch-chains and an intermediate shaft.

The "steam elephant," Fig. 149, constructed by Messrs. Taylor and Co., has three speeds, and the weight rests on blocks of india-rubber. The engineman and steersman stand on one platform behind the driving-wheels, and the engine may run either way. The engine is provided with a winding apparatus, by means of which it can load its own trucks. The boiler is arranged to be as short as possible, with the object of ascending or descending steep hills without uncovering the fire-box or the flue-tubes; it rests on the frame of the engine, and is fixed to it without itself forming any part of the frame. The chimney passes through the dome of the boiler, and the waste heat is to some extent utilised in drying the steam.

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